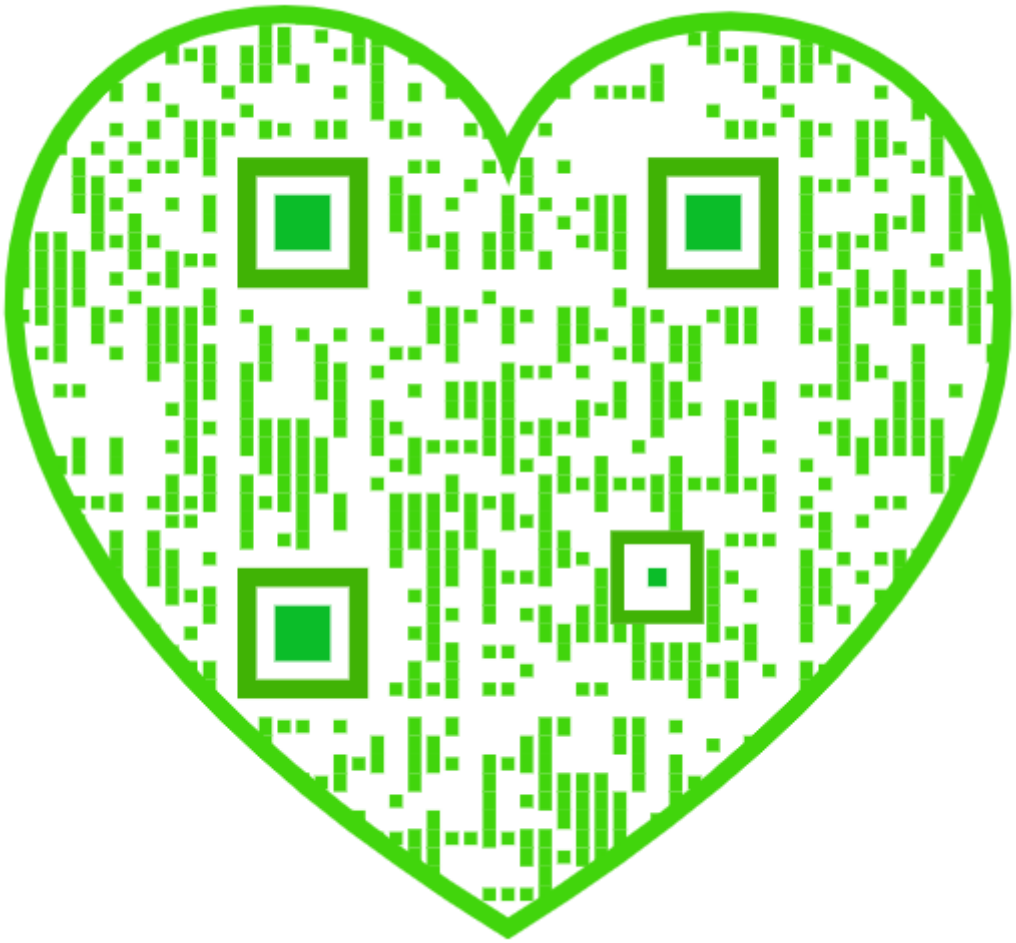
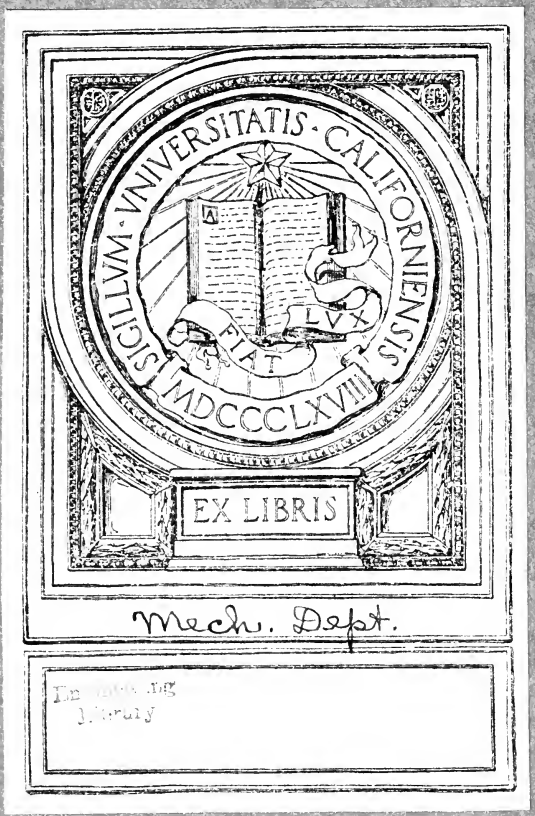




Mech. Dept.

The Public Library

FORGECRAFT

BY

CHARLES PHILIP CROWE
OHIO STATE UNIVERSITY

COLUMBUS, OHIO
R. G. ADAMS & COMPANY
1913

TS225
C7
Engineering
Library

Mech. Dept.

COPYRIGHT 1913
BY
CHARLES P. CROWE

UNIV. OF
CALIFORNIA

THE HEER PRESS
COLUMBUS, OHIO

PREFACE

This book is intended for the student, the apprentice, and the artisan who works at the forge. For any one who cares to understand forgecraft, some things explained here will be found profitable.

The author has found it impossible to complete many of the themes begun in this book, and had no intention of attempting to exhaust the theme when he began writing.

Forgecraft is a fundamental subject and the only argument that fully proves many of its principles is a piece of iron or steel shaped and treated properly. Intelligence rather than great strength is now recognized as the chief requisite for success in this trade. But skill can not be acquired without experience, and while knowledge of the theory is more valuable to the possessor than practical skill, the latter ought to be gained first in order that the understanding may be correct.

To all who would acquire more information on the subject of this ancient art, which is the same now as in the days of Tubal Cain, this book is respectfully dedicated.

C. P. C.

266993

CONTENTS

PAGE

Introduction xi
Definition xi
Forgecraft — Forming — Welding — Fixing — Knowing . . . xi

PART I

CHAPTER I

THE FORGE

Heating Place — Oxidation — Placing Tuyers — Air Pressure — The Fire — Fuels 5

CHAPTER II

TOOLS

Hammers — Anvils — Tongs — Swages — Fullers — Cutting Tools — Flatter — Set Hammer — Punches — Heading Tools — Sledges — Special Tools 10

CHAPTER III

MATERIALS USED

Wrought Iron — Machinery Steel — Crucible Steel — High Speed Steel (Metallurgy — Manufacture — Chemistry) 22

CHAPTER IV

FORMED WORK

Bending Rings and Curves — Stock Calculations — Allowance for loss in Welding — Ornamental Iron Work — Drawing out and Forging Sections — Drawing Tapers 33
Forging Angles and Corners 41
Bolts — Solid Forged — Upset Head — Weld Head — Hand Forged Nuts 45
Reference Tables 51-65

CHAPTER V

HOOKS AND CHAINS

Design — Calculation of Stock — Hand Forged Chain Hook — Grab Hooks — Gate Hook — Hook Formula — Chain Making — Stock — Tests — Heat Treatment 75

PART II

CHAPTER VI

WELDING

Definition — Fluxes — Butt, Split, Lap, T, Corner, Fagot Weld — Ring on Shaft — Eyebolt — Allowance to Weld On — Loss in Welding — Oxidation — Strength — Forging the Weld . . . 85

CHAPTER VII

SPECIAL WLEDS

PAGE

The Swivel — Rope Hook — Turn Buckle — Socket Wrench — Shank Weld — Ornaments — Welding Steel to Iron — Using a Flux — Electric Welding — Thermit Welding — Hot Flame Processes — Cost of Welding — Oxidation Value 98

PART III

Introductory Steel Working — Heat Treatment — Temperature Color Names 109

CHAPTER VIII

TOOL SMITHING

The Heating Fire — Proper Heats — Hammering Steel — Cutting Steel — Machine Tool Forging — Clearance Angle — Bent Tools — Offset Edges — Shank Tools — High Speed Tools — Time and Tool Used 112

CHAPTER IX

HARDENING AND CARBONIZING

Why Steel Hardens —Hardening Crucible Steel — Oxidation Scale — Liquid Baths for Heating Steel — Effect of Heat on Steel — Examination of Fracture — Right Hardening Heat — Critical Temperature — Recalescence — Cooling Baths — Hardening in Oil — Warping and Cracking — Pack Hardening — High Speed Steel — Mushet Steel — Treatment of — Case Hardening — Carbonizing Materials — Guide for Hardening 126

CHAPTER X

TEMPERING

Heat Treatment Summary — Oxidation Color — Graduation of Hardness — Oil Tempering for Tools — Oil Tempered Forgings — Liquid Baths and Methods — Special Tempering Methods — Case Hardening for Colors — Annealing — The Cooling Rate — Guide for Tempering 146

ADDENDA

CHAPTER XI

METALLOGRAPHY

Drawing Showing Critical Points and Recalescence 162
Theoretical Drawings Showing how Iron and Carbon mix forming different Structures in Steel — Cryohydrate — Eutectic Alloy . 170
Alpha Iron — Beta Iron — Gamma Iron — Hardenite — Martensite — Austenite — Carbide of Iron — Cementite — Pearlite — Sorbite — Troostite 172

ILLUSTRATIONS

	PAGE
Steam hammer, 5 ton	2
Forge and fires	6
Cutlery making	8
Cross pein hand hammer, 2 lb	10
Cross pein hand hammer, 3 lb	10
Hammer, ball pein	11
Hammer, carriage ironers	11
Hammer, straight pein	11
Hammer, cross pein	11
Hammer, fitting, Fig. 4	12
Hammer, turning, Fig. 5	12
Anvil model	13
Anvil shape	13
Tongs, pick up	15
Tongs, bolt	15
Tongs, machine tool	15
Tongs, V jaw	15
Tongs, curved jaw	15
Tongs, flat stock	15
Swage, bottom, Fig. 7	16
Swage, top, Fig. 8	16
Fuller, top, Fig. 9	17
Fuller, bottom, Fig. 10	17
Set hammer, Fig. 11	17
Flatter, Fig. 12	17
Square punch	18
Round punch	18
Cold chisel, Fig. 13	18
Hot chisel, Fig. 14	18
Hardie, Fig. 15	18
Blacksmith's punch	19
Hand chisel	19
Sledge, cross pein	20
Sledge, double faced	20
Heading tool	20
Special forging tools	21
Forming dies and jigs	21
Iron Ore, loading	22
Ore, digging, Fig. 2	23
Ore pile, Fig. 3	23
Blast furnace	24
Pig iron bed	24
Puddling furnace	26

PAGE
Puddler at work 26
Pouring crucible steel 27
Bessemer converter 29
Steel billets, Fig. 10 30
Steel grain, Fig. 12 30
Grain size in steel, Fig. 12 30
Wrought iron fiber, Fig. 11 30
Bending over anvil horn 33
Median line, Fig. 2 34
Effect of bending, Fig. 3 34
Ornamental piece 37
Scrolling tools 37
A bending fork 37
Bending a scroll 37
Hammering to make square bar 39
Hammering to draw out end 40
Sharp pointed piece 41
Upsetting a piece 42
Flowing stock to corner, Fig. 9 43
Finishing the outside of a corner, Fig. 10 43
Finishing the inside of a corner, Fig. 11 43
Holding for corner weld 44
Bolt making, Fig. 14 46
Upsetting for a bolt, Fig. 13 46
Making six sides on a bolt head 47
Changing the shape of a round head on a bolt 47
Making a hexagon shape 47
Punching holes 48
Driving a blacksmith's punch through iron 49
Shear cutting with a hot chisel 50
Cutting off with the hot chisel and hardie 50
Expansion curve of iron and steel 59
Photograph of a chain hook 66
Drawing of a chain hook 66
Fullering position 68
Holding to hammer a tapered section 69
Holding to forge an eye for a chain hook 69
Striking to bend a hook 70
Holding to complete the bend for a hook 70
Hammering a wedge shape and turning a hook 71
Grab hook with eye at 90 degree angle 72
Standard grab hook (Left hand in Fig. 8) 72
Forging a shoulder 73
Twisting a square bar 73
Scarfing the end of a piece 76
Ready to weld a ring 76
Ready to finish a ring 76
Holding for a lap weld 88
Holding for a T weld 88
Holding for a corner weld 89

PAGE
Position for swaging 90
The place to strike first 90
Fuller marking 92
Fagot welded forging 93
Weld head bolt making 93
Making a cockeye 94
Welding an eye bolt 95
Scarfed and lapped ring 95
Swivel 98
Rope hook 98
Turn buckle 98
Socket wrench 99
Anvil tool 99
Twisted rods 100
Reverse twist for ornaments 100
Welding steel to iron 101
Steel faced tool 102
Chisel making 114
Cutting end clearance, Fig. 2 115
Using top fuller, Fig. 3 115
Drawing out a tool bit, Fig. 4 115
Drawing out a tool bit, Fig. 5 116
Cutting the angle, Fig. 6 116
Finishing an angle cut, Fig. 7 117
Testing the angle, Fig. 8 117
Testing for side clearance, Fig. 9 118
Testing for angle bend, Fig. 10 118
Fullering for side tool, Fig. 11 119
Offsetting a side tool, Fig. 12 119
Testing for 15° side clearance, Fig 13 120
Fullering for a shank tool, Fig. 14 120
Holding to forge a diamond point tool, Fig. 15 121
Finishing the diamond point, Fig. 16 121
Hot cutting the slope, Fig. 17 122
Forging a long shank tool, Fig. 18 122
Finishing the shank 123
A group of lathe tools 124
A group of planer tools, Fig. 21 125
A group of shaper tools, Fig. 22 125
Medium carbon steel, Fig. 1 127
Low carbon steel, Fig. 2 127
High carbon steel, Fig. 3 127
Hard coke furnace 129
Pipe for heating steel 129
Heat measuring instrument 129
Jig to hold hot mandril 129
Coarse grained steel 131
Steel refined by quenching 131
Steel refined by hammering 131
Partly refined steel 132

PAGE
The way to quench steel 136
Hardening a side tool 137
Muffle furnace 138
Piece ready for pack hardening 138
Case hardened fractures 143
Polishing for temper color 149
Oil tempering appliance 151
Cyanide box 155
Cooling bath 155
Curve showing critical and recalescence heats 162
Steel surface etched natural size 163
Eutectic alloy, (left hand) 165
Mechanical mixture of two constituents, (right hand) 165
Mild steel, polished and etched 166
Rolled iron, polished and etched 166
Broken steel, forged with a light hammer 166
Hammered iron, polished and etched 166
Drawing to show structure of nine point carbon steel 167
Drawing to show structure of twenty-one point carbon steel 167
Drawing to show structure of thirty-five point carbon steel 167
Drawing to show structure of eighty point carbon steel 167
Structure of ferrite 167
Structure of pearlite 167
Structure of high carbon steel 168
Structure of low carbon steel 168
High carbon steel hardened 169
Low carbon steel hardened 169
Nine point carbon steel quenched 169
Drawings to show how steel varies with carbon content—
Low carbon 170
Medium carbon 171
High carbon 171

INTRODUCTORY

FORGECRAFT

The *Forge* is a place where iron and steel are given thermal and physical treatment.

The *Craft* is dexterity and knowledge in giving the required shape and treatment.

Part I. Treats of the tools and materials, with instructions for using them to make certain dimensions and shapes.

Part II. Treats of welding wrought iron and steel, with instructions for preserving the strength of the materials.

Part III. Is on the treatment of steel, with instructions for making types of tools that are in common use.

The subject may be considered under four heads:

First: *Forming*—which is changing the shape of commercial bar stock in line or section.

Second: *Welding*—which is making joints by a direct contact and union of the pieces to be joined.

Third: *Fixing*—which is changing the condition of the material into a desired state of hardness or coherence.

Fourth: *Knowing*—which is from learning about the three kinds of things that are done at the forge.

In part one of this book the things treated are essential to the first part of the subject. There are many other fuels, tools, and *forms* of work equally important, but these have been chosen, and the manner of using the fuel and tools and making the forgings has been described, because they are types of all that is or can be done at the forge without knowing how to make welds or fix the condition of steel. The fundamental principles are the same when heating with other fuels or using other tools.

Drop forging dies were developed from the swages and other tools shown in succeeding chapters, and the power

hammers, with all the appliances used in the forging industry, followed naturally when the methods shown in this book were not powerful enough to handle heavy pieces, or fast enough to duplicate the forms demanded.

In part two, *welding* is described and illustrated as well as the author can do it in black and white on a printed page. The color of the heat and the appearance of the metal can only be learned at the forge, and the author's hands at rest, holding the pieces in position during important stages of the work described in the text, are not as expressive as hands in action.

In part three, the standard cutting tools common in machine shops are shown with instructions and illustrations of the best way to forge them and *fix* in them that condition, or change, in the arrangement of the component parts desired. Each operation plays a part in *fixing* the state of the metal. But the process of hardening and tempering steel is of such great importance that it becomes of chief interest in a great many pieces treated in Forgecraft.

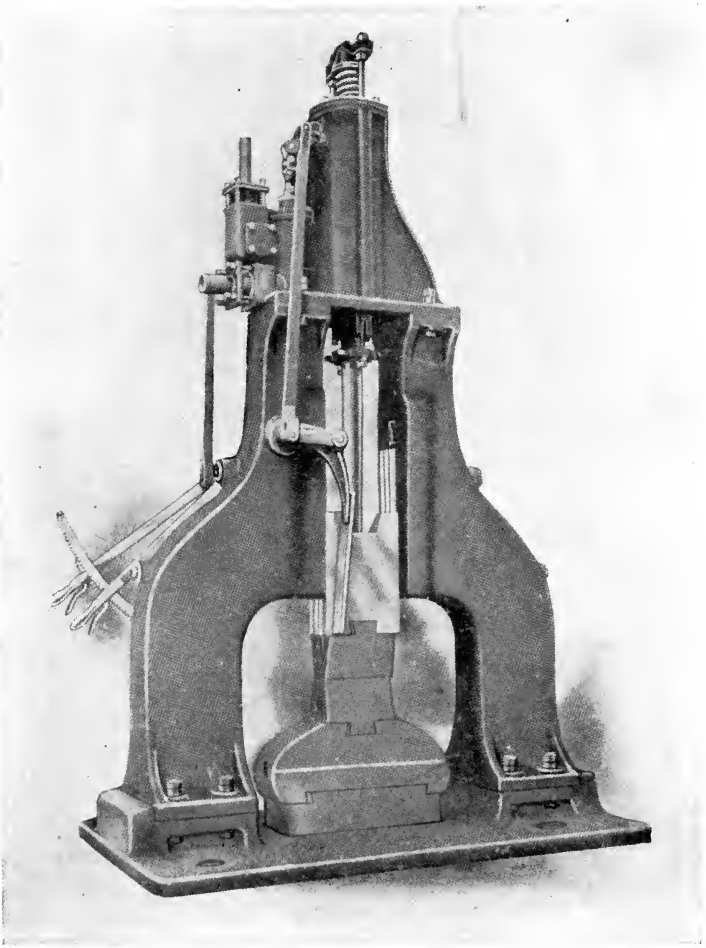
There remains learning from experience, reading, and discussion of the subject. This gives the knowledge essential to successful accomplishment of whatever kind of work there is to be done. There is such a close relation between the three parts into which this text is divided that it is impossible to know one part without learning something of the other. But the subject is progressive and the practice lessons, given in the first two parts, should be understood before attempting to learn to do the things in the third part of the book.

A TEXT BOOK ON

FORGECRAFT

WITH A CHAPTER ON METALOGRAPHY

(1)



FIVE TON STEAM HAMMER.

The piston and attached hammer head weighs 10,000 pounds.

PART ONE

Part one treats of the tools and materials, with instructions for using them to make certain dimensions and shapes.

FORGECRAFT

CHAPTER I

THE FORGE

A PLACE WHERE IRON AND STEEL IS HAMMERED INTO SHAPE

If we should confine ourselves to the forge in the narrow sense of its being merely a thing or place on which a fire might be built and things heated, the subject would not be broad enough; though much might be said and written about this fireplace which is often and not improperly called a forge.

It is better to think of the forge in the older understanding of the word, when it meant a place where iron and steel were made; blooms, billets and slabs of steel or iron used to be made at the forge, which was a great place containing cupolas, furnaces, power presses, hammers, and rolls where the hot billets were finished to sizes required by blacksmiths and other users of commercial bar.

The blacksmith is so called because he works black oxide on the metal, and finishes his work black or unpolished. He is thus distinguished from the metal polisher, the tinsmith, or the silversmith, whose work is finished white or who works in white metal.

The forge, the place where iron and steel are heated and hammered into shape, is the broad sense in which the word should now be used. We find at the forge many things well worth our study.

THE HEATING PLACE

The place to build the fire should be of a size and shape suitable to the work. A small fireplace with a roof of brick or some better non-conducting incombustible material like asbestos, above it, is best for workmen who do only small work, such as tool-dressing and horseshoeing. Some work demands that the heating place must not be covered on account of the height of pieces projecting above the fire while a part is being heated, and some work requires a large resting

place, in which case the hearth about the fire may be wide on all sides. Those matters are of practical value and the details can be worked out by any one preparing to do a certain class of work.

Fig. 2.

But there are other items about the fire and the fireplace which should be considered scientifically as well as practically.

OXIDATION

The blast opening, or tuyere, may be in the bottom of the fireplace so as to direct the air up into the fire, but for heavy work it is better to direct it horizontally into the fire at the bottom, for the vertical blast may work directly through amongst the coals and against the piece to be heated, and not only cool it in spots, but the excess of oxygen over carbon coming in contact with the hot metal destroys some of it and may oxidize it so profusely that it will not be in good condition for forging and can not be welded. With care and skill, the workman using a tuyere giving an upblast of air can keep just enough coals under the piece to split up the currents of air and combine with the oxygen without choking or clogging the blast. So the difficulty mentioned above may be avoided with less fuel consumption for small work than would be required in a horizontal blast.

PLACING TUYERES

When the tuyere, or blast opening, is horizontal at one side, the air currents must cross the bed of fire and be split before they turn upward, so they do not seem to bore holes through the fire as quickly as the up-blast; but as the tuyere irons can be arranged for dumping and cleaning more easily under the fire than at its side, the character of the work alone compels the use of a side blast at many fires where very heavy work is done.

The depth of the tuyere below the hearth must be at least five inches, for the natural place for the piece to be heated is level with the hearth. Long bars to be heated in the middle can not be lower than the edge or hearth of the fireplace, and blocking it up is unnecessary if the hearth is the right distance above the tuyere. This should be right at every forge, and the right depth is always the same in big or in little fires with light or heavy blast pressures.

AIR PRESSURE

The pressure of air blast at the tuyere should not be less than three ounces per square inch. This low pressure is less liable to injure metal that is being heated, as destructive oxidation would occur but slowly, and the mild blast of air will cool the piece before much injury is done. In a high air

pressure of two or three pounds to the square inch, white hot metal exposed to the blast is quickly destroyed.

The hottest place is from five to seven inches above the tuyere; if enough burning fuel is piled upon it, the piece will be in the middle of the fire and that is the hottest place. Therefore, it is the best place to get a heat on the piece.

THE FIRE

The air blast from which we get oxygen passing through five to seven inches of hot fuel (carbon in proper form) furnishes oxygen and carbon in the right proportion to make heat. If it passes through less than five inches of fuel, there is not enough carbon; therefore, the piece we are attempting to heat will oxidize excessively, and if oxygen must pass through more than seven inches of fuel, there is an excess of carbon and consequently slow heating, while in extreme cases of violation of these instructions, it is absolutely impossible to get a welding heat, or a good condition for treating anything.

Fig. 3.

This is true also if the fire is too wide or long. Forge fires should be kept just large enough to surround the piece to be heated with glowing coals. Unburned coal wet packed around the fire will keep it from spreading.

FUEL

The fuel used should be coking coal, as free from sulphur, slate, and other impurities as possible. Any soft coal that

crumbles easily into many sided small particles with bright and shiny surfaces is good smithing coal, if it will coke.

The only way to learn of the coking properties of coal is to try it and see if it cokes. Many blacksmiths do not bank the fire and make a supply of coke for future use. It is not necessary to do so for light work, because the experienced man can char the coal about the rim of the fire as fast as he needs it.

This charred coal which he is constantly making and using as he needs it to replenish the fire and to cover the heating piece is soft coke. Hard coke is made by getting it very hot without burning. Keeping the coal a long time very hot under a bank that is wet enough to prevent consumption makes it into hard coke. This hard coke, made by high heat, requires a very hot fire to make it burn again, and in some large forge fires hard coke, made in coking ovens and crushed to a convenient size, is a most economical fuel; at others, where the fire is small, it burns with such difficulty as to prevent its being used successfully.

The Blossburg or Peidmont coal, from mines which for many years supplied the market with smithing coal, but have long been exhausted, still remains the most common name known to blacksmiths.

CHAPTER II

FORGE TOOLS

A DESCRIPTION OF TYPES OF ALL TOOLS USED IN THE CRAFT

It is an old saying that "all arts depend on the hammer and hand," and the assertion is easily proven. Imagine, if you can, that all the arts of civilized men are destroyed, the factories, forges, furnaces, machines and tools, all gone. We are left to build them up again. How shall we begin? With fire we can produce a lump of iron from its ore, then reverting to customs of the stone age, we can pound the iron with a stone into the crude shape of a hammer. With our present knowledge of how to use metals, we would not waste time making very convenient stone hammers with depressions in the sides for the thumb and finger, as the ancients did before they learned to make the depressions deep enough to meet through the stone and insert a stick for a handle in the hole (this being a great discovery to them and doubtless marking an era in advancement of industrial art). We would merely select a convenient stone or stones with which to work our lump of iron in a sort of hammer shape with a hole through it for the handle. With the hammer and hand we could soon forge other things, and the work of rebuilding the tools and machines of civilized industrial arts would proceed rapidly, but it would always depend as it does now on the hammer and the hand.

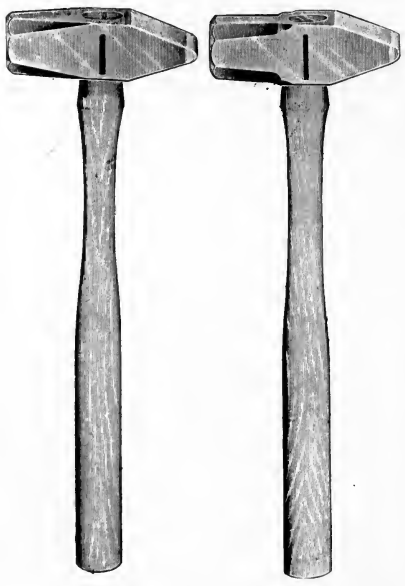


Fig. 1.

After the hand hammer, Fig. 1, the next tool necessary is the anvil, which is now made in several slightly different shapes, and by different methods. See Fig. 6.

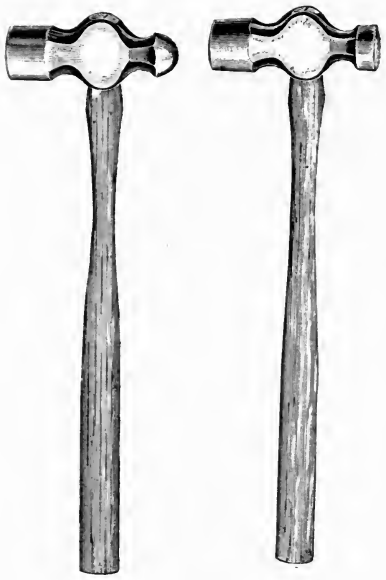


Fig. 2.

Then we must have a pair of tongs to hold our forging while it is being worked. See Fig. 7.

The hammer, the anvil and the tongs are the three tools essential to forgework, and we shall consider them in a general way.

Claw hammers, sledges, masons' hammers, ship mauls, wood choppers' mauls, pavers' hammers, etc., are specialties which may be described some other place. Of all shapes the hand hammer is the simplest, and was formerly the most common forging hammer. Now the Ball Pein hammer is the choice of most blacksmiths for general work. See Fig. 2.

The Cross Pein hammer, with its short wedge-shaped end flattened at right angles with the eye, and the Straight Pein, with its wedge-shaped end flattened parallel with the handle, are types of hand hammers in common use for distinctive purposes. See Fig. 3. The carriage ironer's hammer in Fig. 2 is almost a Ball Pein, and would be chosen for its special work only. Others are especially adapted to turning and fitting horseshoes, and are familiar shapes to many workmen. See Fig. 4.

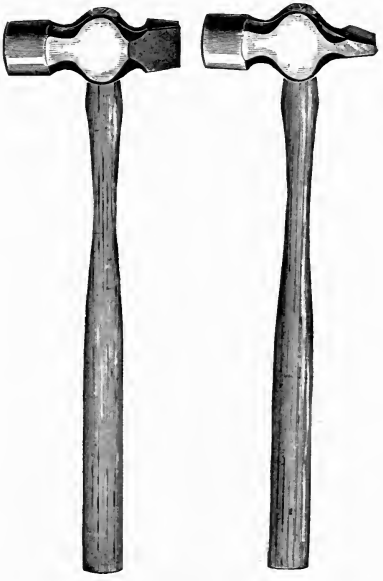


Fig. 3.

Hand-made hammers used to be very popular with the best smiths, but now drop forged and turned hammers are so much

cheaper and come so near being as good, that it does not pay to make them by hand. A poor, cheap hammer should never be bought by a mechanic. Buy hammers of a reputable dealer and pay a fair price and you will usually get good ones.

Fig. 4.

Fig. 5.

A good hammer that has been battered and used a great while will always be dented some on the face, especially around the edge, before small particles are broken out of the corners. If large chips break off the face of a hammer before it shows signs of wear and battering, it was too hard or was made of poor material, for a good hammer cannot be broken without being dinged and battered first. It follows, of course, that if the hammer in service becomes battered until a large burr or flange forms around the corner of the face without breaking off, the hammer was tempered too soft. Sometimes if such hammers are rehardened and tempered properly, they are all right, but often they will break and chip out in large flakes from the edge, because the material is not the right kind for hammers.

So in a hammer we can learn something about the trouble with all hardened and tempered steel; make it hard enough and it will break easily; leave it soft and it will batter quickly. Therefore we must choose a medium. A good hammer must be made of a kind of steel that will dent and batter slightly before it breaks with hard pounding, after it has been made so hard that a file will scratch it with difficulty. A good hammer seldom wears out in good use, but is ruined by abuse, like the

Englishman's horse, "It isn't the 'unting as 'urts the 'osses, it's the 'ammer, 'ammer, 'ammer on the 'ard 'ighway.

ANVILS

The anvil, shaped very much as we know it, is an ancient tool. Many hundred years ago they were made about the same shape they are today. Age alone would not make us respect a machine or tool, but it is a significant fact that very little change or improvement has been made in anvils during several centuries of use.

Fig. 6 shows the model with these principal dimensions of standard anvil used by leading anvil makers.

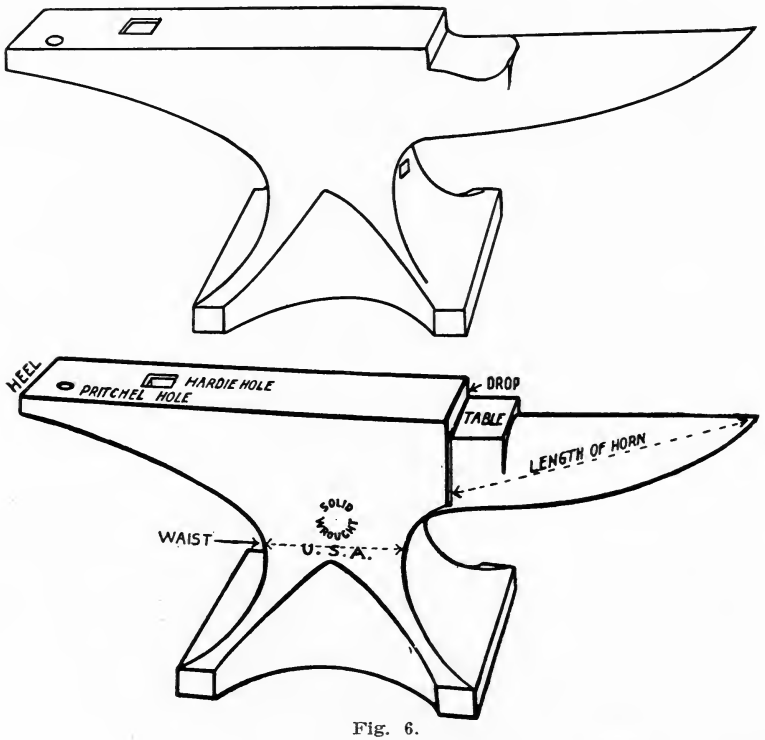


Fig. 6.

Face.	*Horn.*	*Waist.*	*Heel.*	*Drop.*	*Hardie Hole.*	*Approx. Weight.*
3¼x14½″	10″	4½″	13/16″	13/16″	7/8″	100 lbs.
3½x15¾″	11″	4¾″	7/8″	7/8″	15/16″	125 lbs.
3¾x17″	11¾″	5⅛″	15/16″	15/16″	1″	160 lbs.
4x18″	12½″	5½″	1″	1″	11/16″	200 lbs.
4¼x19″	13¼″	5⅞″	11/16″	11/16″	11/16″	225 lbs.

The dimensions and weights shown on page 13 are only an average and will vary some either way.

Some study of the lines of the anvil model which the author helped design will show that it is well adapted for universal use and there is little prospect for any great change in the shape of this tool.

It is a tool so simple in form, yet adapted to so many different forgings, that special anvils are seldom made. Almost any work that can be done on anvils of special shape can be done on the standard form, and the specialties often interfere with regular work being done.

The so-called saw-makers anvil is little more than a rectangular block of metal with a hardened face; it is more convenient for the purpose of straightening saws than a standard anvil, but could not be adapted to a general class of work.

Large anvils with two legs have been made, but are not in common use, and the demand for them is not great.

The regular anvil is most solid over the middle, here it is rigid where the most work is done. Here directly over the waist it will best endure the heavy pounding of sledges, and over the heel forked pieces can be forged, while almost any curve or bend can be made around the horn. The table is a convenient unhardened place for cutting through upon with a chisel, and pieces held end down resting on the table can be steadied against the end of the anvil face, while they are struck on the upper end as in upsetting short pieces of stock, the hardie hole, and pritchel hole are conveniently placed for anything they are to be used for.

TONGS

The tongs should be well made and kept fitted to the work they are designed to hold. Drop forged tongs of steel are now made so cheaply that making them by hand is not such common practice as it was some years ago. The best drop forged tongs like Fig. 7 are made each side of one piece; that is, the jaw and reins are forged solid. For hand tongs the best way is to forge the jaw of heavy material and weld on lighter stock for the reins.

If you cut the rivet that holds the two parts of a pair of tongs together, you will find that the jaws are forged alike, both are right handed. In a pair of jaws made to go together

all of the offsets, projections, curves and dimensions are the same and in the same direction. It is a common mistake for a beginner to forge what he calls the right hand and left hand

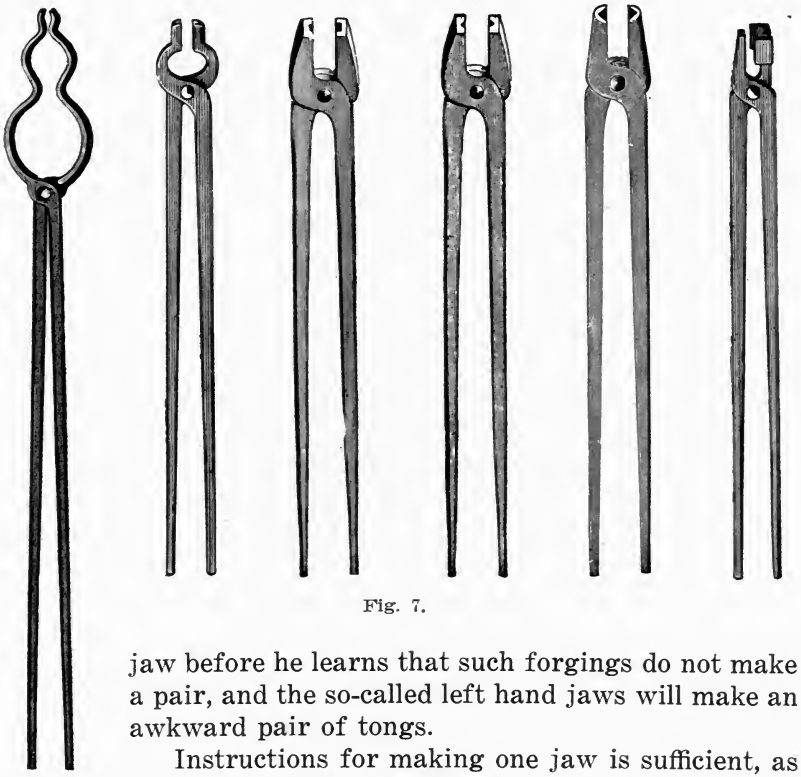


Fig. 7.

jaw before he learns that such forgings do not make a pair, and the so-called left hand jaws will make an awkward pair of tongs.

Instructions for making one jaw is sufficient, as the other should be exactly like it; then, if the first one is a good forging, a nice pair of tongs will be made.

FORGING TONGS

To make a pair of one-quarter-inch tongs, take a piece of one-inch square material of convenient length and forge a jaw eye or stub rein on one end of it as follows: Get a long heat (five or six inches) and make a fuller mark on one side about three-eighths of an inch deep, the right distance from the end to leave stock for a jaw, say three-quarters of an inch; turn the bar one-fourth over toward the left, and make another fuller mark a little deeper and just back of the first depression; turn again toward the left, and make a third

fuller mark about one-half inch back of second mark three-eighths of an inch deep. Now place the first fuller mark, turned down with the middle of it over the near corner of the anvil, and draw out the jaw by hammering to width and thickness desired. Next put the jaw from you over the anvil with the middle of the second fuller mark down and opposite the far corner, and spread the eye with the hammer. Then turn the third fuller mark down on the far corner of the anvil, and draw down the stub end for handle or rein three or four inches long, cut off this forging and make another exactly like it. Weld on the reins, punch the rivet holes and fit the jaws together, then rivet them. Get them red hot again and adjust them to the piece they are intended to hold, open the jaws wide and put them in the water while hot. Close and open them while cooling and you will have a nice, easy-working, close-fitting pair of tongs.

An experienced man can forge one side of a pair of tongs like this at one heat. It is easier to make the captain than the mate, for slight variations in size of the two sides make bad work, so the mate should be exactly like the captain.

A good way for the beginner to do is to try a forging like this with cold lead for practice, then with swedes iron, which is very soft, a quite serviceable pair of tongs can be forged easily, but steel tongs wear better.

SWAGES

Swages are made in sizes the measure of the width of the groove which may be half round, octagon, square or any shape desired, the shanks or stems on the bottom swages are forged to fit the hardie holes of anvils. See Fig. 7.

Fig. 7.

Fig. 8.

The groove in the top swage is like that in the bottom swage. Handles should be made of wood long enough to allow holding the hand far enough from hot work, and the swage should not be wedged on the handle. Fig. 8 shows a top swage without a handle.

Fig. 9 is the top fuller, the curved end is half round made of any size required. Fig. 10 shows a bottom fuller which, as seen, must have a square shank fitted to the hardie hole of the anvil on which it is to be used in the same manner as the swage. When a piece of material that is being forged requires a shoulder on opposite sides of a bar, the piece is rested across the edge of the bottom fuller. The top fuller is then placed on top of the forging and struck with a sledge until the fullers form a depression on opposite sides of it to the depth required. The smooth rounded edge of the fullers do not cut or nick the forging, but leave fillets which are strong support to shoulders left where large and small sections of forgings join. Square shoulders and sharp angles are much more easily broken than rounded corners, so the inside angle or shoulder should always have as large a fillet as possible in it. The fullers are, therefore, very important forging tools, frequently used on both iron and steel work. The top fuller is often used to make depressions on the upper side of a forging as it lies flat on the anvil. From the bottom of this depression made in a thick piece, thin sections can be drawn out, leaving a fillet in the corner, as shown by illustrations in succeeding chapters. This tool is indispensable to the forge man in making machine tools for the lathe or planer. In places where the fillet can not be left inside of a corner, the forging is finished with a square faced set hammer. Fig. 11.

Fig. 9.

Fig. 10.

Fig. 11.

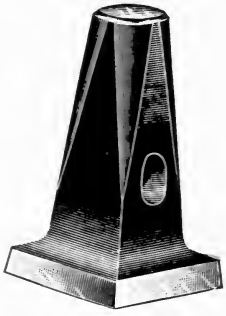


Fig. 12.

The flatter is a tool that is used in much the same way as a set hammer, but, as the face of a flatter is larger than the body of the tool, as shown in Fig. 12, there is enough spring or give to the edges of the extended corners to make

it less liable to sink into the forging and leave tool marks. It is, therefore, more of a smoothing or finishing tool for straight work, while the set hammer is distinctly a forging tool, often used to change the dimensions and shape of the piece on the anvil. The top fuller and the set hammer are perhaps the most necessary and useful tools in forge work requiring a helper.

CUTTING TOOLS

The distinctive difference between the cold chisel and the hot chisel is seen in Figs. 13 and 14. A common size for the smith's use is one and one-half inch square at the eye. The pole and bit are of equal length on both tools. The bit of a cold chisel is drawn down as a wedge, one-fourth inch thick at the thin end, and after it is hardened and tempered it is ground to a sharp edge on an angle of sixty degrees with the median line.

Fig. 13.

Fig. 14.

The hot chisel being intended for use on metal that is softened by heating, and often used for slicing away portions that are not wanted on a piece that is being forged, has a bit less than half as thick as that of a cold chisel and the edge is ground at just half the angle, or thirty degrees.

A hardie, Fig. 15, may be ground at either angle, according to the kind of work most frequently done with it. Hardies are sometimes used for nicking cold pieces so they can be broken at the nick, and at other times a sharp thin hardie is convenient for cutting hot metal. Bent and forked shapes, curves and angles, are sometimes correctly made by using the hardie as a forging tool, over which they can be held as it rests in place on the anvil. Pieces held against its top edge, flat side, or corner may be struck with the hammer and brought to a proper shape.

Fig. 15.

Fig. 16.

In Fig. 16 are two punches which require wooden handles by which they can be held in place by the smith as they are struck by the helper's sledge. The manner of making holes with these punches is similar to that required for successful work with the hand punch shown in Fig. 17 and is described in Chapter IV. If a ½″ hole is required in material ½″ thick, the standard hand punch is used. The stock is 80 point carbon steel; ⅝″, octagon in shape because it is best for the hand hold; 10½″ long, so the hand that holds it on the hot metal to be punched will not be burned, and the blow of the hammer will be more effective than it would be on a longer punch. It is tapered from its diameter of ⅝″ to ¼″, and shaped to suit the hole, a true straight sided taper, 3″ long and perfectly flat on the small end with sharp corners all around. If there is not enough taper to a punch of this kind, i. e., if it is more than 3″ long and the diameter given above, its sides are so parallel that it will stick in the hole after being driven down, and considerable difficulty in withdrawing it may be experienced. On the other hand, if there is too much taper or the end is not flat with corners sharp to cut their way into the metal, it will be difficult to drive and hard to make a clean, straight hole through the piece. The hammer used on this punch should not weigh less than 1½ nor more than 2 pounds, for blows delivered with a lighter hammer on the head of this punch would not be very effective at the end, 10½ inches away. A heavier hammer is apt to bend the punch, or drive it so suddenly into the material that there is no time for the hot metal to flow into the new form it is being compelled to take. The flow of metal must be carefully considered by every forge man, or many tasks will be very difficult, and his forgings will be of poor quality. With the punch described here, used in the manner more fully shown in a succeeding chapter, 7/16″ holes through ½″ metal are easily made. The cold chisel shown in Fig. 17 is made of the same kind of material as the punch.

Fig. 17.

Heading tools, like Fig. 18, are very useful when making upset head bolts. For medium sizes, 7/16″ to 15/16″ bolts,

Fig. 18.

the hole in the tool should be 1/32″ larger than the diameter of the shaft of the bolt.

Fig. 19 shows blacksmith sledges. They are sometimes made with the pein straight, or ball, like the hammers in Figs. 2 and 4. A good weight and kind for ordinary forge work is an eight-pound cross pein sledge.

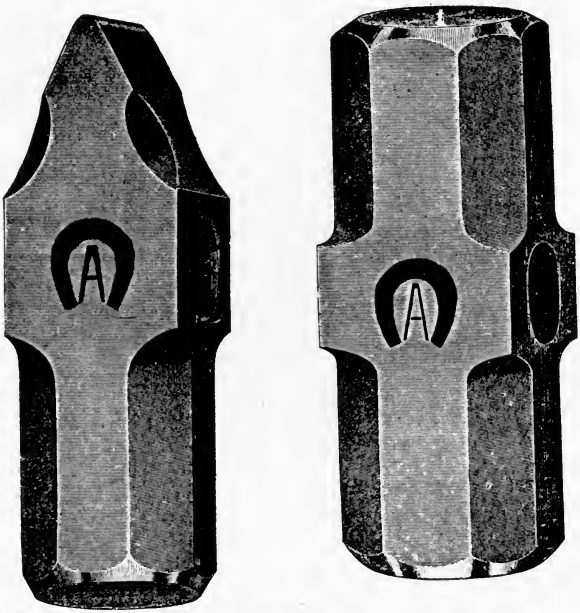
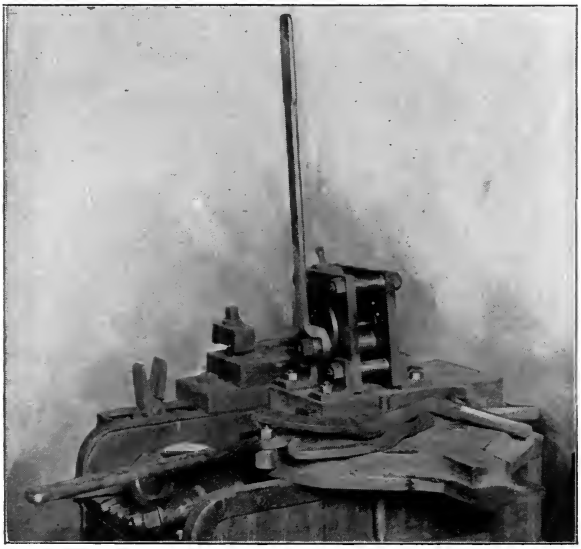


Fig. 19.

The special forging tools, Fig. 20, shown on the opposite page must be seen and used in order to be fully understood, and no attempt is made in this book to describe them fully. Every successful forge man is able to make the special

tools required for his particular work, and only the regular tools common to all shops and such operations as are fundamental and necessarily performed in all forge rooms, either



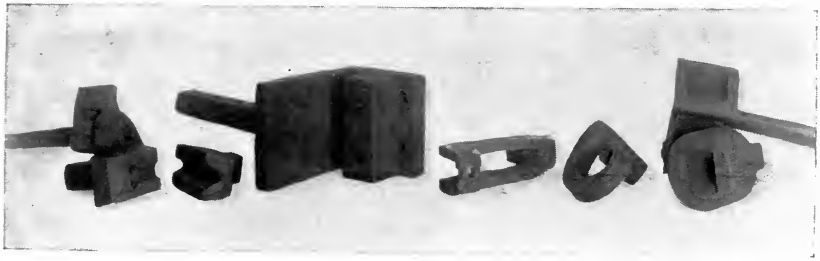


Fig. 20.

in the production of the identical things described in these pages, or so similar as to require the same kind of operation and method of proceeding with the work, will be treated of in this book.

CHAPTER III

MATERIAL USED FOR FORGINGS

Forgings are made of either iron or steel. The careful selection of materials is the first thing of great importance after the forge is properly equipped. As there are only two general kinds of material to be used, it would seem a simple problem at first glance to learn just which material would be best for any forging, but when we begin a study of the question, we find it a more complicated one than it at first appears to be, for wrought iron of at least three kinds must be considered, and steel cannot be thought of intelligently, without a definite knowledge of two kinds that are distinctly different. Wrought iron designated as common iron, refined iron and Swedes iron conveys a distinct classification of the metal. And the information that steel

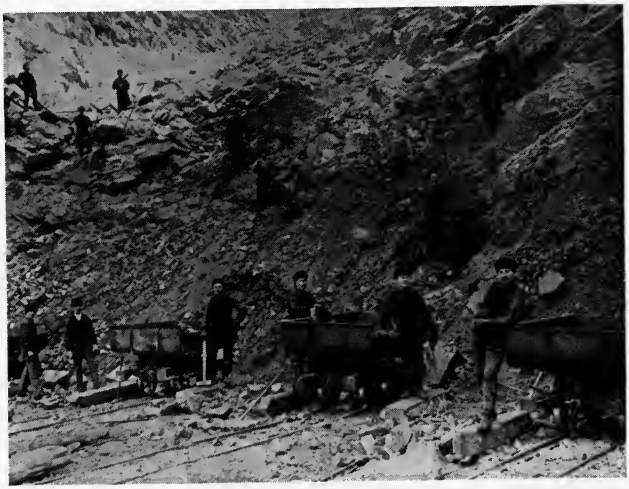


Fig. 1. Loading Ore.

is either crucible tool-steel, or converted machine-steel, gives us some idea of its properties that will aid in selecting the material for forgings.

METALLURGY

The metallurgist must learn about the different kinds of iron ore and fuel, but for our purpose any information of

that kind would have no practical value, so we say that iron ore, properly treated, will furnish us with the iron or steel we want. The first step in the process is the same for all kinds of material.

Fig. 2. Digging Ore.

Fig. 3. Ore Pile.

Iron ore most commonly found is like red brown earth, soft and crumbly like rich loam, it is shoveled into a conveyance, hoisted to the top of the blast furnace, and dumped in

along with the fuel — coke, and the flux — limestone. The heat of the furnace melts the iron in the ore, and it sinks to

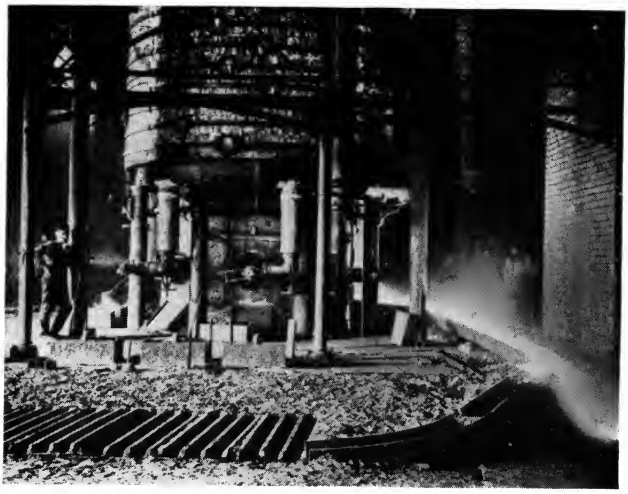


Fig. 4. Blast Furnace.

the bottom of the furnace, the flux keeps the other products from becoming sticky thick and pasty, enough to clog the

Fig. 5. Pig Iron Bed.

furnace, and causes them to float as a liquid on top of the iron. Finally the refuse is drawn off as slag, while the

heavier iron flows out of a lower tap hole in the furnace, and is cooled in bars or slabs of a size convenient to handle. This is called pig iron and looks like a very rough cast iron; in fact, it is cast iron, having been cast or poured when liquid into a mold or bed of sand, where it cools and solidifies. Pig iron is the stuff out of which cast iron and malleable iron pieces are made, as well as that of which all of our forging materials are manufactured.

MANUFACTURE

It is the purpose of this chapter to give such general information about the manufacture and the consequent properties of these five kinds of material as will help the "forge man" to select and work his material with greater satisfaction to himself, as well as in such a way as to produce better forgings. The man who works at the anvil will most assuredly be happier if he knows a good deal about the metal he is working than if he knows little, and although the science of metallurgy is so great and becoming so complicated, that no one man can know it all, any one who wishes can get a good understanding of these five classes of material, and may then add the sixth, which is high speed metal, but this being only a subdivision of crucible or tool steel, it was not named at the beginning of this article, though it has become of such great importance for tool forgings, that it must have its place.

CHEMISTRY

The chemical reactions that take place in the blast furnace, and the mechanical appliances with which a modern blast furnace is equipped are subjects of great interest, involving much study on the part of one who wishes to understand them in detail. To us they may seem very simple, since we need only know what primitive men knew perhaps four thousand years ago—a hot fire separates the metallic iron from the earthy matter. They knew, too, that a blast of air made the fire hotter, so they had blast furnaces, and puddling furnaces and crucible furnaces, this was all there was to it four hundred years ago. One man could know all that was known then of metallurgy. For even as late as a hundred years ago all there was to iron manufacturing was to make pig iron by putting ore in a very hot fire in a tall furnace,

with a blast under the fire and then make wrought iron bars that were afterward used as such or carbonized by the blister or the crucible process. These processes do not eliminate sulphur phosphorus and other injurious elements that may be in the pig. Hence good material depends on the selection of pure ore.

WROUGHT IRON

Wrought iron is made out of pig iron by puddling it on the floor of a furnace with the fire blown over the iron, the fire being at one end of the furnace the pig iron being put in at the other. When the iron gets sticky or pasty the puddler

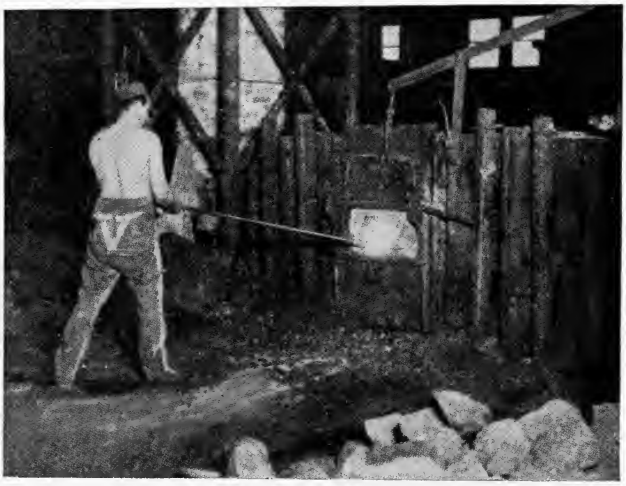
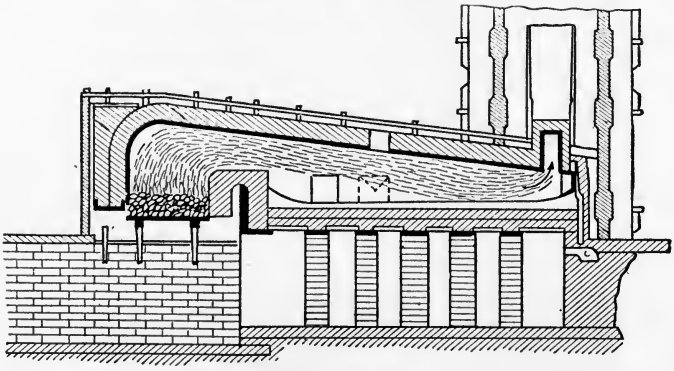


Fig. 6. Puddling Iron.



PUDDLING FURNACE.

Fig. 7.

knows it as having "come to nature" and it is pulled up into a ball. The chemical reaction reduces carbon, etc., but leaves other injurious elements in the iron that is taken out of the furnace and hammered or rolled into a bar. This bar is known as common wrought iron.

STEEL

Tool steel is made of wrought iron by melting and carbonizing it in a crucible. The iron bar is cut into scraps that will go into a clay or plumbago pot about six inches across and a foot high. This pot, called a crucible, filled with these scraps, is put into the furnace. When the iron is melted and carbonized it is poured into a mold and becomes crucible cast steel or tool steel. See Fig. 8.

These three processes — blast furnace, puddling and crucible—were in use several hundred years ago and are in use today. They are the essential steps in the progress of the metal iron from the ore to the best commercial bar of iron or steel. From these anything can be forged which it is possible to make at the forge.

Pouring Crucible Steel.

Fig. 8.

In olden times when the artisan, instead of the scientist, was responsible for the product of a furnace, the best workmen made the best iron or steel; just as some blacksmiths, who run their own shops and do their own work, make better forgings than others in the same line of business. In these modern times, mills produce material of different grades according to orders scientifically designating the quality wanted.

Common wrought iron is simply the cheapest product of the iron mill and puddling furnace.

Refined wrought iron is the same kind of material, with the flaws, seams, cracks and more of the gross impurity or slag worked out of it by cutting, piling, welding, and rolling or hammering. Common iron bars are sometimes piled and welded six times before they are sold for refined iron. The

chemical constituents remain the same. The work that has been done on it, makes the price additional for refined iron.

HOT SHORT AND COLD SHORT

If there is too much sulphur in it, the bar is hot short, and is liable to be broken while bending at a red heat on a one inch radius.

If there is too much phosphorus in it, it is cold short, and may crack if bent cold to a three foot circle.

There is too much sulphur and phosphorus in all American ore, and the iron and steel makers do not take it out. When iron or steel that is very soft or very tough is wanted, the kind that is never hot or cold short, but always the same reliable metal, Swedes iron must be bought, because the ore of that country has no phosphorus and practically no sulphur in it.

IMPORTED WROUGHT IRON

Norway and Swedes iron are the same thing, and the methods of manufacture are practically alike in those countries and in this. Import duty must be paid according to the size of bars. Bars smaller than one inch by one-half inch are usually rolled down in this country from larger imported bars. A metal tag stamped "Swedes iron" must be attached to each bundle of about one hundred pounds. One by one-half inch bars and larger are each stamped "Made in Sweden." This iron is not stiff enough for some forgings, but is very easily worked. The best crucible tool steel is made in this country out of imported Swedes wrought iron.

IRON OR STEEL?

Puddling pig iron purifies it more than any other process, therefore before the best steel can be made, iron is puddled and made into wrought iron. Puddled iron contains no carbon, so carbon is added in the crucible or pot in which the wrought iron is melted for the purpose of making it into steel. It is not simply the carbon in the iron that makes it steel, but the process of manufacture. Wrought iron is formed out of a pasty or sticky mass taken from the furnace. Steel is formed out of a liquid mass poured from a container. This is always true no matter what kind of steel is meant. The distinctive difference between wrought iron and steel is that one is made from pasty masses, the other from liquid.

MACHINERY STEEL

The Bessemer and open hearth processes of steel making eliminate the puddling, and handle large quantities of melted pig iron in one receptacle or vessel. This receptacle in the Bessemer works is like a large pot or jug, capable of holding several tons of liquid metal. See Fig. 9. In the open hearth process it is a huge furnace in which many more tons of pig iron or scrap may be melted at one time and drawn out of a tap hole. In either of these methods the quality of the charge, the manner of heating, the kind of fuel and the material with which the vessel containing the liquid iron is lined, affect the properties of the metal produced. But the product is iron

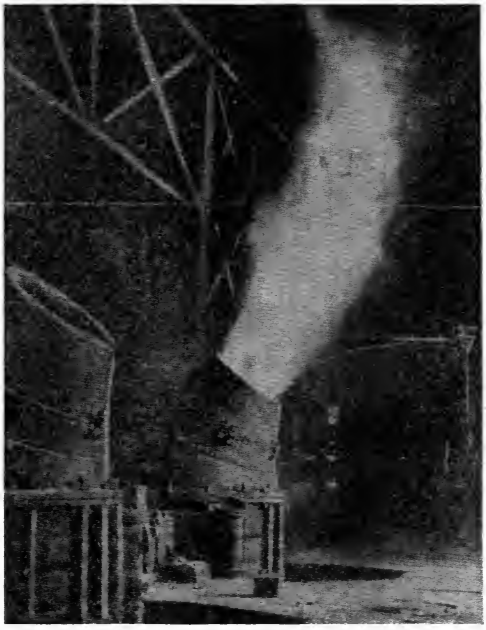


Fig. 9. Bessemer Converter.

converted into steel, converted in the liquid state, under the influence of heat. The difference between converted steel and crucible steel is as great as the difference between oleomargarine and butter; good, old fashioned, clean, sweet butter can never be replaced by the oil extracted from fats, and converted steels can never take the place of crucible steel. Pud-

dled iron out of which crucible steel is made is like the cream that makes good butter. All of our wrought iron is puddled

Fig. 10. Steel Billets.

iron, made out of pasty masses. All of our steel is made from liquid masses, therefore iron is fibrous in its structure, the crystals are stretched into threads held lengthwise in the bar, so wrought iron has a fibrous structure, while steel has not. Fig. 11 shows the fiber and slag magnified in wrought iron. Fig. 12 is a magnified section of steel grains.

Fig. 11. Wrought Iron.

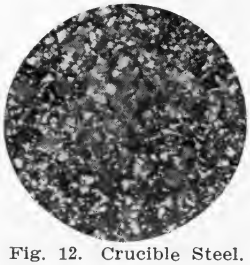


Fig. 12. Crucible Steel.

USES

For hooks and chains where absolute reliance must be placed in a given weight of metal, and for many forgings of a similar character, iron is used exclusively. Anchor chains of a large size should never be made of steel. Locomotive frames forged of good iron, put together in such a way at the welds that the fiber of the iron runs in the direction of the greatest strain, are lighter and better than any steel frame that ever has or probably ever will be made.

But the use for steel as forging material is great, first, because it is cheaper than iron, and second, because it can be made into very large pieces in very simple and easy ways, while very large iron forgings must be built up by welding. Steel ingots can be cast of almost any size, and then forged down. Steel bars do not twist as easily as iron bars, hence for crank shafts and things of a like nature, where the torsion strain is great, steel is preferred to iron.

Some forgings aside from cutting tools are made of crucible steel, but for nearly all purposes except tools, there are grades of converted steel known as structural or machine steel that are more easily forged and are equally good when finished.

Wrought iron costs 10 per cent to 20 per cent more than the cheapest steel. Its claims to superiority over dead-soft steel consist in its purity and the presence in it of slag. Just how much advantage the slag is, has never been proven; it helps give the metal a fibrous structure which, perhaps, increases its toughness and its resistance to breaking under bending, or under a sudden blow or shock. When under greater strain than it can withstand, wrought iron stretches more uniformly over its entire length than steel. Some think that the slag also assists in the welding of the material, but this is doubtful and it is probable that the easy weldability of wrought iron is due to its being low in carbon.

The properties of wrought iron are the nearest to those of chemically pure iron of any commercial material, notwithstanding its slag, which because it is mechanically mingled with the metal does not interfere with its chemical or physical behavior. Therefore wrought iron is greatly preferred for electrical-conductivity purposes and as a metal with high magnetic power for use as armatures of electro-magnets, etc. The advantages I have mentioned, the conservation of engineers and the capital previously invested in puddling furnaces are the chief factors in keeping alive the manufacture of wrought iron. It was freely predicted that the invention of the Bessemer and open-hearth processes would bring about the extinction of the puddling process, but these prophecies have never been fulfilled, although the importance of wrought iron has waned very greatly in fifty years.

JUDGING A PIECE OF FORGED WORK

The value of a forging made of these materials depends on the perfection with which it will do the work for which it was intended. If it is the right shape it has been formed correctly, and there is little difficulty in determining this, for by comparison with a sketch or template, or a piece known to be right, this factor of the value is decided.

The size is another factor more difficult for an inexperienced man to determine, usually a forging should be less than one-sixteenth of an inch more than the dimension given for each part. Commercial rod and bar stock is over-size less than one-thirty-second of an inch, but forgings that are to be machined should be larger. Practically all hand made forgings should have as much over-size as it is customary to make rods and bars in the steel and iron mills. This explains why the divisions on the measuring instruments used at the forge need not be less than one-sixteenth of an inch. All parts of hammer work that are not slightly over the dimension given in sixteenths of an inch are called "scant" or imperfect forgings, except in certain parts that will be noted.

The third factor to be considered when judging this kind of work is its fixed condition, which is closely related to its strength. This cannot be known without breaking the piece —a sacrifice that cannot be made of all forgings—therefore it is necessary to know how the surface should appear, and depend on inspection. A smooth blue-black hammered skin of oxide, free from loose scale and pits, indicates that the forging is in good condition, and if there are no visible signs of a crack or flaw it is said to have full strength. Gray-white shining surfaces indicate that a piece was hammered when cold, and that it may have been injured by such treatment. Heavy loose scale and deep pits indicate that it was injured by excessive oxidation in the fire, or was made too hot for the final hammering.

The fixed conditions of tempered steel is indicated on its polished surface by the color of the oxide formed by the last temperature to which it was raised. But as a knowing workman can produce any appearance that has been mentioned, regardless of the internal structure or composition of the material, more depends on his honesty and skill than outsiders are aware of, for when the three factors, shape, size, and apparent strength, of forgings are correct, they are said to have full value.

CHAPTER IV

BENDING RINGS AND CURVES, FORGING ANGLES, BOLTS AND NUTS AND STOCK CALCULATION

To bend a ring or curve in metal the work should usually be started on one end, as shown in Fig. 1. If the curve is to be a complete circle forming a ring made by hand and hammer

Fig. 1.

on an anvil, when half the piece is bent to the correct radius, as near as the eye of the workman can see, work should be started on the other end, and when both halves are curved over the horn of the anvil into a semi-circle, the two ends will meet if the radius is correct, making the circle or ring complete.

STOCK CALCULATION FOR RINGS

To find the length of a piece of stock needed for a circle, the thickness of the material must be added to the inside diameter of the ring, and the circumference given in the table on page 56 is the length required. Or, it may be calculated thus: If a three-inch ring is to be made out of one-half inch stock, it means that the finished work will measure four inches across from out to out and 3½ inches

from center to center of stock, and the length of a piece required to make it is the measure of the circumference on the middle of the piece. This is an imaginary or median line (see dotted line in Fig. 2): that half of the material outside this line must be drawn out or stretched, and the half thickness of the metal inside the median line must shorten or upset when the material is bent. We do not need to take this into consideration during our stock calculation, but must find the length of the median line as follows: $3'' + \frac{1}{2}'' = 3\frac{1}{2}''$ $3\frac{1}{2}'' \times 3\ 1/7'' = 11''$, the length of stock required to make a ring of the size wanted with the ends butted together, and because the metal usually does not shorten enough on the inside, these corners will touch first, as in Fig. 3, and the ring will be a trifle oversize, but if they are slightly beveled so that the ends can come together making a close joint the diameter will be correct.

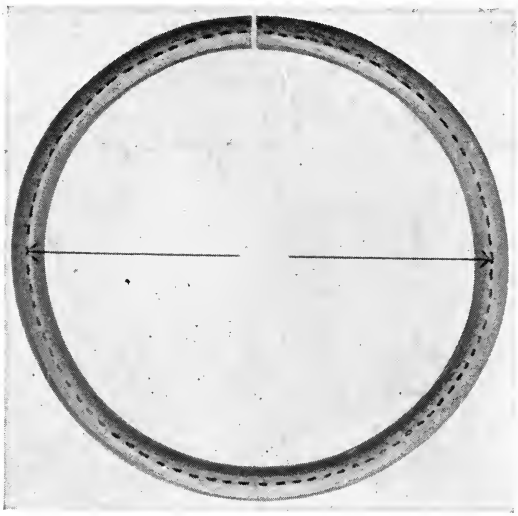


Fig. 2.

Fig. 3.

ALLOWANCE FOR LOSS IN WELDING

If the ring is to be welded an allowance for loss must be made, so some extra length will be required. How much this loss by welding will be depends upon several things. The kind of material and the appliances with which the work is done make some difference. In general, there is less material lost in welding steel than iron, for steel welding heats are not so high as for common iron, and if the forge, fire, and tools

are of the best and so arranged that the kind of welding to be done can be heated quickly and handled rapidly, there need not be much waste in welding small sizes; but if the weld is large or a difficult one to get in the fire, and the appliances are not of the best for handling the work, more allowance for loss of material should be made. The chief factor, however, is the experience and skill of the operator.

A ring weld, such as we have in consideration, can be made of good iron or low carbon steel without any appreciable loss, that is, the piece of stock eleven inches long and one-half inch in thickness can be curved to a circle, scarfed on the ends without upsetting, lapped and welded so that it will measure with the instruments commonly used in the forge room to a three-inch ring, one-half inch thick all the way round. But if very fine measuring instruments are used accurately, some loss of material would be discovered, so if the ring is to be machined to exact size, an allowance of one-quarter inch (half the thickness) should be added to the length of the piece as an allowance for welding.

This allowance for welding is a constant that must be chosen according to the judgment and experience of the workman, and is more fully explained in Chapter 6, usually one-half of the diameter or thickness of the stock is sufficient. But we have seen heavy iron wagon wheel tires carefully measured to a length on the inside after bending, exactly equal to the circumference of the rim of the wheel and one full thickness of the tire added as an allowance for the loss in welding, and when the lap was long, the welding heat taken high, so that it was soft and worked out easily, there was very little excess thickness left at the weld when the tires were fitted. On the other hand, light steel tires are often measured in the same way, and nothing allowed for loss in welding, and when they are fitted there is no apparent lack of material at the weld.

TO DETERMINE LENGTH OF CURVES

There is no way to calculate mathematically with sufficient accuracy the length of a piece required to make large circles, irregular curves, and bent shapes that the smith is sometimes called on to form. In such cases the common method of using a measuring wheel which can be rolled along

the required curve, and then an equal number of revolutions over the straight bar is the best way. In fact, it is the only method accurate and convenient enough to get the correct measure of tires and such large rings or bands as are used for wooden cisterns and the like. But when the curve is very small or very irregular and the measuring wheel can not be used, string measure is resorted to for hub bands, maul rings, etc., which are practically round; and for coupling pole or double tree bands, which may be rectangular in shape with round corners, correct measure can be obtained with a cord or soft wire by putting it around the piece to be banded, and then laying off an equal length on the straight piece of material of which the band is to be made. In such cases as we are considering the take up of material in bending will usually be enough to make the band a "shrink fit," that is, when it is expanded by heating, it can be put to place and when it is cooled off, it will be a very tight fit.

See table of expansion of iron and steel on page 59. If a loose fit is desired, it will be necessary to make an allowance for loss in welding and take up in bending. Boiler makers add three times the diameter of the sheet to the mathematical circumference for the take up in rolling.

To get the measure of a straight piece necessary to make curves which begin small and increase to wide sweeping bends, such as are seen in ornamental scroll work, etc., the best way is to use a piece of small soft wire. The scroll must be laid out or drawn on paper or board, see Fig. 4A, or perhaps on a metal face plate, where it can be measured with the soft wire, then the straight piece is cut the right length. Work should be begun on the small end of the scroll. Ornamental work made up mostly of curves and crooked lines is the easiest to make, because the irregularities of lines that are intended to be straight and parallel are more noticeable than slight irregularities in curves, hence greater care and skill is necessary to produce the accurate work that makes straight parts pleasing to the eye than is required on the curved parts. Here if the curves formed are smooth and artistically progressive, the work will be pleasing.

In designing a piece of ornamental work, some of the openings should be large and others small. If they are of even size, the piece will become tiresome to look at, but if the piece is well designed and well executed, it is like a tree that always

pleases with its symmetry of form and unequal distances between the branches.

Fig. 4A.

MAKING ORNAMENTAL IRON WORK

The only special tools needed for ornamental work are scrolling irons, or, as they are sometimes called, bending forks. The one with the square shank, shown on the floor to the left in Fig. 4A, can be used in either the anvil or vise, and can be adjusted for long or short curves on thick or thin material by moving the steel pin into any of the holes; the common form of bending fork, like the one being used in Fig. 4B, is forged

Fig. 4B.

solid and does very well for ordinary work, but sometimes it is necessary to have different widths between the forks, and the one with adjustable pins can be used to better advantage.

The sketch of one lower third of the ornamental work shown in Fig. 4A, is tacked on the wall to the left of the picture.

The total height of the piece is 55 inches, and the width 22 inches over all at the base. The three scrolls uniting in each foot of the base are made of $\frac{3}{4}'' \times \frac{3}{16}''$ iron. The flat scrolls between the legs are made of $\frac{3}{4}'' \times \frac{1}{8}''$, and the small round pieces are $\frac{3}{16}''$. The basket on top is made of $\frac{1}{2}'' \times \frac{1}{8}''$ iron, the inside curve of the lower ends of the six scrolls in the basket are soldered to the flat sides of a hexagon nut, tapped to fit $\frac{3}{8}''$ gas pipe, on which it is screwed until the end of the pipe sticks up far enough to receive the gas burner fitting. The lower end of this pipe is about three inches from the floor and is fitted to receive rubber tubing. These fittings can be removed and an electric wire drawn through the pipe would give that kind of light, or an oil lamp can be placed in the basket, as it appears in the picture. The bands at A and B are Babbitt metal cast in place, covering the binding wire. At C is a wrought iron clip shrunk on over the rivet, which holds the three scrolls in place at this point. The labor on this piece of work amounts to fifty dollars. Twenty-five dollars should be added for the design. So an original pattern of this character is well worth seventy-five dollars.

STOCK CALCULATION FOR SHAPES

The best shop practice is to use the tables of weights to find the equivalent portions. See pages 57, 58, 60, 61 for tables.

To determine the length of stock of one size required to make a given length of another size or sectional area. *Rule*: Find the weight of the size and shape that is to be forged into another size or shape and divide by the weight of the shape and size to which it is to be changed.

Example: Round stock, 2″ in diameter, is to be forged flat, $\frac{3}{8}''$ thick, 4″ wide, 6″ long.

2″ round = 10.68 $\frac{3}{8}'' \times 4'' = 5.10$ $10.68 \div 5.10 = 2.09$.

Therefore 1″ of the round stock will make 2.09″ of the

flat part, the .09″ may be allowed for loss due to the heating and hammering each 2″ of the required length, and, as $6 \div 2 = 3$, it will require 3″ of the 2″ round to make 6″ of $\frac{3}{8}'' \times \frac{3}{4}''$.

Round stock 1″ in diameter or smaller can be hammered into square bars $\frac{1}{8}''$ less in thickness than the round.

Forged sizes vary by sixteenths of an inch, and another $\frac{1}{8}''$ must be taken off, when using sizes of round over 1″, and so on up through the sizes in common use, as follows:

Round 1″ and under makes square $\frac{1}{8}''$ less.
Round 2″ and under makes square $\frac{1}{4}''$ less.
Round 3″ and under makes square $\frac{3}{8}''$ less.
Round 4″ and under makes square $\frac{1}{2}''$ less.
Round 5″ and over may not conform to this rule.

DRAWING OUT AND FORGING SECTIONS

When drawing or stretching a piece, it should be held on the anvil at right angles and level with its face, (see Fig. 5) then the hammer blow should fall on a plane horizontal

Fig. 5.

with the anvil face which is slightly convex and will cause the metal to flow toward the ends of the piece more rapidly than toward the sides. If the piece to be drawn out is enough larger than the required diameter to permit the indentation, it will stretch more rapidly by holding on top of the horn of the anvil and striking it just over the resting place; the round top of the horn acts as a fuller pushing the metal out endwise, and there is less spreading toward the sides. A similar effect can be obtained by holding and striking, as shown in Fig. 6, so the round edge of the anvil helps to draw the metal

toward the end, and the piece lengthens rapidly under hammer blows effectively delivered.

The material must be kept at a forging heat. It should be made as hot as it will stand without injury and the most of the drawing out should be done while it is white

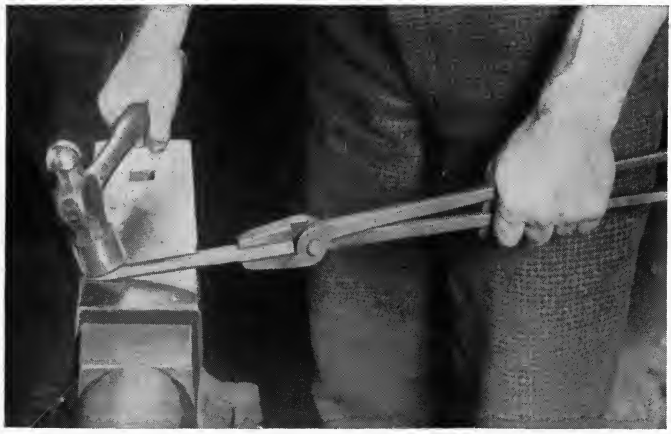


Fig. 6.

hot. The hammering may be continued while the metal is at a yellow heat, but when wrought iron cools down to red heat it splits easily, and at dark red heat it is liable to be brittle. Steel also is sometimes dangerously brittle, and should not be hammered when dark spots can be seen after the hammer blows.

Pieces should always be hammered on four flat sides, and alternate sides should be turned up to get the effect of hammer blows. The side that rests on the anvil is chilled more rapidly than the others, and the side that is struck with the hammer is lengthened and spread out the most, so it is necessary to turn it over often and hammer opposite sides equally to make the physical structure the same on all sides of a forging. Wrought iron fibre is easily separated, and internal ruptures that do not show on the surface are liable to be caused by improper heating, handling, or hammering. Each hammer blow should be heavy enough to affect the piece through half of its diameter. It should be turned over for each side to get the same effect, and kept as hot as it will stand. This is all a skilled workman can do. One may know

the theory of foregcraft, but without practice he cannot learn to make good forgings.

DRAWING TAPERS

To draw out a sharp point, as shown in Fig. 7, the end should be made sharp by hammering four sides equally until the point is as sharp as desired. The piece should be kept at a convenient angle with the anvil face, as shown in

Fig. 7.

Fig. 6, and the blows delivered so that the far edge of the hammer lands in line with the edge of the anvil and over the end of the piece. After the point is sharpened square, it can be changed to a flat tapered point by hammering two of the sides until they spread to the desired width, or by hammering the corners down a round point can be made of it. When the section of the tapered point has been made into the shape desired, the length of the taper can be increased, if necessary, by hammering further back on the stock until the length and angle of the taper are correct. This is the fastest and best way to proceed with hand made forgings of this type.

The length of stock required to forge tapered points of a given length and shape, can not be determined from tables, but must be calculated mathematically, making proper allowance for loss of stock in forging. Much depends on the experience and judgment of the workman in this as it does in drawing out, upsetting, spreading and welding stock. The human element can not be determined without experience, but must be taken into account with the calculations for stock, made elsewhere in this text.

STOCK FOR ANGLES

For solid forged angles the calculation of stock is very simple. Measure one side from the outside corner to the end, the other side from the inside corner to the end, and add the two lengths together. Or measuring on the median line,

we find the same result. If an angle is to be forged of ¾" stock, each side to be four inches long on the outside, it would take a piece seven and one-fourth inches long to make it; if it must be full sized when finished, perhaps an allowance of one-eighth of an inch for loss in forging should be made, this allowance, like that of the welding, depends upon the method and the operator; and if a small curve or fillet is to be left on the inside there must be some excess of material over our calculation allowed.

FORGING A CORNER

The chief difficulty in a forging of this character is to get the full corner on the outside without making a "cold shut" at the inner corner. If a nick is allowed to start on the inside of the piece, some of the grains or fibers are broken, allowing more strain to come on the next particles, so they get broken and a crack may be worked nearly through the corner by the time the piece is finished. A skillful and experienced workman can forge this crack shut, and in cooling the metal contracts on it so that it can not be seen, then it is a dangerous weak point of a forged corner called a "cold shut." But if the piece is upset first, as in Fig. 8, and care is taken to get the initial bend over a rounded place instead of a sharp corner on the anvil, and if the piece is kept a little out (not in), that is, at an obtuse angle while the outside corner is being worked up, as in Figs. 9 and 10, and is only brought to a right angle at last. Then the forging can be finished, as shown in Fig. 11, sound and strong.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

CORNER WELDS

Owing to the care and skill required to produce solid forged corners in iron or steel, they are frequently welded, sometimes two separate pieces are welded at the corner. This is the best way to make a strong, stiff corner when the angle is toward the edge of a wide piece. Fig. 12 shows two pieces

Fig. 12.

held in position for making a welded corner. See Chapter VI for further instruction on welding.

Different methods of scarfing for such welds may be followed, but the direction of the weld line through the corner is important.

A very nice way to fill the outside corner on thick pieces is to bend the piece without upsetting and work the corner true on the inside, then cut a gash with a hot chisel clear across the outside corner and drive in a blunt, thick wedge and weld it solid. This can frequently be done quicker than the upsetting necessary to produce a full corner without welding, and is as good a way or better in some cases. It is like welding a toe calk on a horseshoe; fasten it to the place by a spur driven into the larger piece, then get a welding heat on the entire part and forge it to the required shape. This is called welding on a "Dutchman" to build up a corner, or putting in a "Dutchman" to fill a crack or close a lap that has refused to weld without it, and is good practice. The dimensions of corner forgings are usually taken on the outside, where the over size is allowed.

CALCULATION FOR BOLTS

The length of a bolt is measured under the head. The thickness of the head is equal to the diameter of the shaft. The width of the head is equal to the diameter of the shaft multiplied by one and one-half, with one-eighth inch added as a constant for standard hand forged bolts.

Example: Calculate the stock for a square head 1″ bolt, 6 5/8″ long.

1×1 1/2 = 1 1/2+1/8 = 1 5/8″ square. Find the weight of equivalent portions in the table, page 58, 1 5/8″ square = 8.978. 1″ round = 2.670. 8.978 ÷ 2.670 = 3.36 inches. In the table of decimal equivalents find the .36 is but .05 more than 5/16″, therefore 3 5/16″ of 1″ round will be required for the head of the bolt 1″ thick if it is made by upsetting round stock. 6 5/8″, length of shaft, + 3 5/16″, required for head, equals 9 15/16″ of 1″ round stock required to make the bolt.

If a solid forged bolt is required the solution is similar, for if 3 5/16″ of round stock will make 1″ of 1 5/8″ square, then 1″ of 1 5/8″ square will make 3 5/16″ of 1″ round, and as 6 5/8 ÷ 3 5″16 = 2, allow 1″ for the head and 2″ for the shaft, and the bolt can be forged out of 1 5/8″×1 5/8″ stock, 3″ long. Solid forged bolts are better than upset head bolts and welded head bolts are poorer. The stock can be calculated and the way to weld heads on bolts can be learned by reference to Chapter VI.

KIND OF MATERIAL AND INSTRUCTION FOR FORGING

Bolts—Solid forged

Low carbon machinery steel is best for solid forged bolts. Stock of a size and shape required for the head may be selected, or round bar stock, large enough to form the head by flattening the right number of sides to give the shape, is often more convenient to get. Determine the length of stock required, then with the top and bottom fullers forge a groove or neck marking the head portion from the shaft; hammer the part for the shaft on four sides until it is square, equal in diameter to that required for the round bolt shaft, then hammer the corners along the full length of stock used for the shaft, and after it is well rounded with the hammer, finish

the shaft with the top and bottom swages to exact size and perfectly round.

Bolts—Upset head

The best refined wrought iron is preferable for this kind of forging. Swedish iron being the purest is less liable to "cold shut" where the head and bolt shaft join. For this method of bolt making a heading tool and its use is shown in Fig. 14. After that portion of stock required for the head is enlarged by upsetting, see Fig. 13, enough to prevent it going through the hole in the heading tool,

Fig. 13.

the shaft of the bolt is put through the hole (which should be 1/32″ larger than the diameter of the shaft for medium sizes, i. e., 7/16″ to 15/16″) and held as in Fig. 14. After it is hammered to the right thickness, the round shaped head can have the flat sides made on it with the hammer by holding it as shown in Figs. 15, 16 and 17, illus-

Fig. 14.

Fig. 15.

Fig. 16.

Fig. 17.

trating the making of a hexagon on the anvil. Notice that after two flat places are made on opposite sides of the round, these flat places can be held at an angle of 30 degrees with the anvil face and a level hammer blow will make the other side at the proper angle with them for a six-sided or hexagon bolt head.

Bolts — Weld head

Select any weldable material and use care to make good welded joints. This is the best way to make very long bolts by hand. Usually such bolts can be large enough to compensate for any weakness caused by welding, and they can be made cheaply. The best way to prepare and handle this kind of forging is shown in Chapter VI, Fig. 8.

Hand Forged Nuts

Swedish iron is preferable for this kind of work. A hole should be punched near the end of a bar, as shown in Figs. 18 and 19. After the small end of the punch is located at the right place, as shown in Fig. 18, it should be held perpendicular and driven two-thirds through the bar as it rests on the solid face of the anvil; then if the punch is taken out and the bar turned over quickly, a dark raised spot where the hot iron is chilled by the cold punch and anvil face can be seen on the other side, and the end of the punch should be placed on this spot and driven part way through the bar again in the same manner as at first. Now the piece should be moved to the position

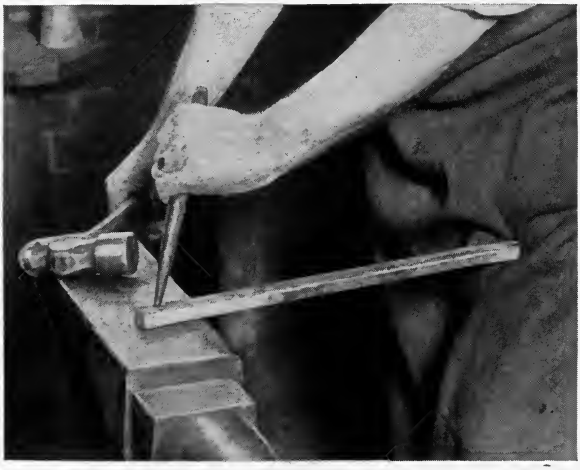


Fig. 18.

shown in Fig. 19 over the pritchel hole and the punch being driven through will force a piece of metal from the bar and a clean hole will be made. The end of the punch used for this kind of work should be flat — not sharp pointed — and it is tapered from stock 1/8" larger than the size of the hole, to the small end, which is equal to one-half the diameter of the hole. The length of taper is six times the length of the hole, as it depends on the thickness of the stock through which the hole is to be punched. For other punches for hot work, see Chapter II, page 18.

Fig. 19.

The stock for the nut is cut from the bar with a hot chisel after the hole is punched, and if the nut is to be a hexagon it should be cut with six sides, as shown in Figs. 20 and 21. The punch must be driven in the hole and kept there while the sides of the nut are flattened and trued by sufficient hammering. After the outside faces of the nut are finished, the punch should be driven into the hole exactly far enough to make it the right size, first on one face and then the other. This leaves the hole slightly smaller in the middle than it is at each end, which could be corrected by driving a drift punch having parallel sides and the right diameter through it, but ordinarily this is not necessary in such forgings of small size made by hand.

The standard size for hand forged nuts is the same as the bolt head, given in this chapter on page 45. The size of the hole in the nut is an inside dimension and should not be made over size. This is one of the exceptions to the practice of forging over-size mentioned in Chapter III, page 32.

Fig. 20.

Fig. 21.

For Reference.

Diameter multiplied by 3.1416=circumference.
Circumference multiplied by .3183=diameter.
Radius multiplied by 6.2831=circumference.
Square of the diameter multiplied by .7854=area.
Diameter multiplied by .8862=side of equal square.
Area of a rectangle=length multiplied by breadth.
Doubling the diameter of a circle increases its area four times.
Side of a square multiplied by 1.128=diameter of circle of equal area.
Surface of a sphere=square of diameter multiplied by 3.1416.
Area of a triangle=base multiplied by ½ the altitude.
Area of a sector of a circle=one-half the length of the arc multiplied by the radius of the circle.
1 cubic foot of water weighs 62 1-3 pounds and contains 7½ gallons.
1 gallon of water (U. S. Standard) weighs 8 1-3 pounds.

To find the capacity (U. S. gallons) of cylindrical tanks, square the diameter expressed in inches, multiply by the length and by .0034.

The pressure of still water in pounds per square inch against the sides of any pipe, channel or vessel of any shape whatever is due solely to the "head" or height of the level surface of the water above the point at which the pressure is considered, and is equal to .43302 lb. per square inch or 62.355 lbs. per square foot for every foot of head.

Boiler Horse Power: The evaporation of 30 lbs. of water per hour, from a temperature of 30° F. into steam at 70 lbs. gauge pressure.

One pound of water evaporated from and at 212° is equivalent to 965.7 British Thermal Units.

To find the number of square feet of heating surface in tubes: Multiply the number of tubes by the diameter of a tube in inches, by its length in feet, and by .2618.

To find safe working pressure of boiler: Multiply 1-6 of tensile strength of plate by the thickness of the thinnest plate in inches and divide by ½ the diameter of the boiler. This is for single riveting, to which add twenty per cent for double riveting when all the holes have been DRILLED.

TENSILE STRENGTH OF METALS

Metal.	Pounds per sq. inch.	Metal.	Pounds per sq. inch.
Aluminum	23,000	Lead—Cast	1,800
Aluminum—bronze	80,000	Pipe	2,100
Antimony	1,000	Manganese bronze—Cast	57,000
Bismuth	3,200	Rolled.	105,000
Brass—Cast	20,000	Platinum, wire	53,000
Wire	49,000	Phosphor bronze—Cast	38,500
Copper—Cast	22,500	Wire	96,000
Wire	60,000	Steel—Cast	60,000
Gun Metal (9 cu., 1 tin)—		Wire	120,000
Cast	32,000	Tin—Cast	4,600
Wire	90,000	Wire	7,000
Iron—Cast 16,000	23,500	Zinc—Cast	5,500
Wrought 58,000	95,000	Wire	20,000

STANDARD SPECIFICATIONS FOR SPECIAL OPEN-HEARTH PLATE

Adopted by the Ass'n. Am. Steel Manufacturers, July 17, 1896.

Steel shall be of four grades—*Extra Soft, Fire Box, Flange or Boiler and Boiler Rivet Steel.*

EXTRA SOFT STEEL

Ultimate strength, 45,000 to 55,000 pounds per square inch. Elastic limit, not less than one-half the ultimate strength. Elongation, 28 per cent. Cold and Quench bends, 180 degrees flat on itself, without fracture on outside of bent portion. Maximum Phosphorus, .04 per cent; maximum Sulphur, .04 per cent.

FIRE BOX STEEL

Ultimate strength, 52,000 to 62,000 pounds per square inch. Elastic limit, not less than one-half the ultimate strength. Elongation, 26 per cent. Cold and Quench bends, 180 degrees, flat on itself, without fracture on outside of bent portion. Maximum Phosphorus, .04 per cent; maximum Sulphur, .04 per cent.

FLANGE OR BOILER STEEL

Ultimate strength, 52,000 to 62,000 pounds per square inch. Elastic limit, not less than one-half the ultimate strength. Elongation, 25 per cent. Cold and Quench bends, 180 degrees flat on itself, without fracture on outside of bent portion. Maximum Phosphorus, .06 per cent; maximum Sulphur, .04per cent.

TEST PIECE FOR SHEARED PLATES

All tests and inspections shall be made at place of manufacture prior to shipment.

The tensile strength, limit of elasticity and ductility shall be determined from a standard test piece cut from the finished material. The standard shape of the test piece for sheared plates shall be as shown. On tests cut from other material the test piece may be either the same as for plates, or it may be planed, or turned parallel throughout its entire length. The elongation shall be measured on an original length of eight inches, except when the thickness of the finished material is $^{5}/_{16}$ inch or less, in which case the elongation shall be measured in a length equal to sixteen times the thickness; and except in rounds of $\frac{5}{8}$ inch or less in diameter, in which case the elongation shall be measured in a length equal to eight times the diameter of section tested. Four test pieces shall be taken from each melt of finished material; two for tension and two for bending.

Material which is to be used without annealing or further treatment is to be tested in the condition in which it comes from the rolls. When material is to be annealed or otherwise treated before use, the specimen representing such material is to be similarly treated before testing.

Every finished piece of steel shall be stamped with the melt number.

All plates shall be free from surface defects and have a workmanlike finish.

STANDARD GAUGE.

U. S. STANDARD GAUGE.					BIRMINGHAM GAUGE.			
No. of Gauge	Thickness in Inches		Weight Square Foot		No. of Gauge	Thickness in Inches	Weight Square Foot	
	Fractions	Decimals	Iron	Steel			Iron	Steel
7-0's	1-2	.5	20.00	20.4				
6-0's	15-32	.46875	18.75	19.125				
5-0's	7-16	.4375	17.50	17.85				
0000	13-32	.40625	16.25	16.575	0000	.454	18.22	18.46
000	3-8	.375	15.	15.30	000	.425	17.05	17.28
00	11-32	.34375	13.75	14.025	00	.38	15.25	15.45
0	5-16	.3125	12.50	12.75	0	.34	13.64	13.82
1	9-32	.28125	11.25	11.475	1	.3	12.04	12.20
2	17-64	.265625	10.625	10.8375	2	.284	11.40	11.55
3	1-4	.25	10.	10.2	3	.259	10.39	10.53
4	15-64	.234375	9.375	9.5625	4	.238	9.55	9.68
5	7-32	.21875	8.75	8.925	5	.22	8.83	8.95
6	13-64	.203125	8.125	8.2875	6	.203	8.15	8.25
7	3-16	.1875	7.5	7.65	7	.18	7.22	7.32
8	11-64	.171875	6.875	7.0125	8	.165	6.62	6.71
9	5-32	.15625	6.25	6.375	9	.148	5.94	6.02
10	9-64	.140625	5.625	5.7375	10	.134	5.38	5.45
11	1-8	.125	5.	5.1	11	.12	4.82	4.88
12	7-64	.109375	4.375	4.625	12	.109	4.37	4.43
13	3-32	.09375	3.75	3.825	13	.095	3.81	3.86
14	5-64	.078125	3.125	3.1875	14	.083	3.33	3.37
15	9-128	.0703125	2.8125	2.86875	15	.072	2.89	2.93
16	1-16	.0625	2.5	2.55	16	.065	2.61	2.64
17	9-160	.05625	2.25	2.295	17	.058	2.33	2.36
18	1-20	.05	2.	2.04	18	.049	1.97	1.99
19	7-160	.04375	1.75	1.785	19	.042	1.69	1.71
20	3-80	.0375	1.50	1.53	20	.035	1.40	1.42
21	11-320	.034375	1.375	1.4025	21	.032	1.28	1.30
22	1-32	.03125	1.25	1.275	22	.028	1.12	1.14
23	9-320	.028125	1.125	1.1475	23	.025	1.00	1.02
24	1-40	.025	1.	1.02	24	.022	.883	.895
25	7-320	.021875	.865	.8925	25	.02	.803	.813
26	3-160	.01875	.75	.765	26	.018	.722	.732
27	11-640	.0171875	.6875	.70125	27	.016	.642	.652
28	1-64	.015625	.625	.6375	28	.014	.562	.569
29	9-640	.0140625	.5625	.57375	29	.013	.....	.....
30	1-80	.0125	.5	.51	30	.012	.....	.....
31	7-640	.010985	.4375	.44625	31	.01	.....	.....
32	13-1280	.01045625	.40625	.414375	32	.009	.....	.....
33	3-320	.009375	.375	.3825	33	.008	.....	.....
34	11-1280	.00859375	.34375	.350625	34	.007	.....	.....
35	5-640	.0078125	.3125	.31875	35	.005	.....	.....
36	9-1280	.00703125	.28125	.286875	36	.004	.....	.....
37	17-2560	.00664062	.265625	.2709375	37	.....	.....	.....
38	1-160	.00625	.25	.255	.....	.....	.....	.....

All sheets of iron and steel are rolled to U. S. standard gauge unless otherwise ordered.

The low temperature (as compared with iron) at which steel plates have to be finished, causes a slight springing of the rolls, leaving the plate thicker in the center than on the edge. This is especially noticeable in plates less than ⅜ inch thick and over 66 inches wide, which may be of full thickness on the edge and yet be as much as ⅛ inch thicker in the middle.,

VARIATION ALLOWABLE

For all plates ordered to gauge, there will be permitted an average excess of weight over that corresponding to the dimensions on the order equal in amount to that specified in the following table:

ALLOWANCES FOR OVERWEIGHT FOR RECTANGULAR PLATES WHEN ORDERED TO GAUGE

Plates will be considered up to gauge if measuring not over $^1/_{100}$ inch less than the ordered gauge.

The weight of one cubic inch of rolled steel is assumed to be 0.2833 pound.

PLATE ¼ INCH AND OVER IN THICKNESS.

THICKNESS OF PLATE. Inch.	WIDTH OF PLATE.		
	Up to 75 Inches. Per Cent.	75 to 100 Inches. Per Cent.	Over 100 Inches. Per Cent.
¼	10	14	18
5/16	8	12	16
3/8	7	10	13
7/16	6	8	10
½	5	7	9
9/16	4½	6½	8½
5/8	4	6	8
Over 5/8	3½	5	6½

PLATE UNDER ¼ INCH IN THICKNESS.

THICKNESS OF PLATE. Inch.	WIDTH OF PLATE.	
	Up to 50 Inches. Per Cent.	50 Inches and Over. Per Cent.
⅛ up to 5/32	10	15
5/32 " 3/16	8½	12½
3/16 " ¼	7	10

VARIATION ALLOWABLE

The variation in cross-section or weight of more than 2½ per cent from that specified will be sufficient cause for rejection, except in the case of sheared plates, which will be covered by the following permissible variations:

Plates 12½ pounds per square foot or heavier, up to 100 inches wide, when ordered to weight, shall not average more than 2½ per cent variation above or 2½ per cent below the theoretical weight. When 100 inches wide and over 5 per cent above or 5 per cent below the theoretical weight.

Plates under 12½ pounds per square foot, when ordered to weight, shall not average a greater variation than the following:

Up to 75 inches wide, 2½ per cent above or 2½ per cent below the theoretical weight. 75 inches wide up to 100 inches wide, 5 per cent above or 3 per cent below the theoretical weight. When 100 inches wide and over 10 per cent above or 3 per cent below the theoretical weight.

TABLE OF DECIMAL EQUIVALENTS

OF 8THS, 16THS, 32NDS AND 64THS OF AN INCH, FOR USE IN CONNECTION WITH MICROMETER CALIPERS.

8THS.	64THS.
1-8=.125	1-64=.015625
1-4=.25	3-64=.046875
3-8=.375	5-64=.078125
1-2=.50	7-64=.109375
5-8=.625	9-64=.140625
3-4=.75	11-64=.171875
7-8=.875	13-64=.203125
	15-64=.234375
16THS.	17-64=.265625
1-16=.0625	19-64=.296875
3-16=.1875	21-64=.328125
5-16=.3125	23-64=.359375
7-16=.4375	25-64=.390625
9-16=.5625	27-64=.421875
11-16=.6875	29-64=.453125
13-16=.8125	31-64=.484375
15-16=.9375	33-64=.515625
	35-64=.546875
32NDS.	37-64=.578125
1-32=.03125	39-64=.609375
3-32=.09375	41-64=.640625
5-32=.15625	43-64=.671875
7-32=.21875	45-64=.753125
9-32=.28125	47-64=.734375
11-32=.34375	49-64=.765625
13-32=.40625	51-64=.796875
15-32=.46875	53-64=.828125
17-32=.53125	55-64=.859375
19-32=.59375	57-64=.890625
21-32=.65625	59-64=.921875
23-32=.71875	61-64=.953125
25-32=.78125	63-64=.984375
27-32=.84375	
29-32=.90625	
31-32=.96875	

MISCELLANEOUS

For the area of a circle . . .	×	square of diameter by .	.7854
For the diameter of a circle . .	×	circumference by . . .	.31831
For the circumference of a circle	×	diameter by	3.1416
For the surface of a ball . . .	×	square of diameter by .	3.1416
For the cubic inches in a ball .	×	cube of diameter by . .	.5236
For the side of an equal square	×	diameter by	.8862

CIRCUMFERENCE AND AREAS OF CIRCLES

Diameter Inches	Circumference Inches	Area Square Inches	Diameter Inches	Circumference Inches	Area Square Inches	Diameter Inches	Circumference Inches	Area Square Inches
1/16	.19635	.00307	4 1/2	14.137	15.904	9 5/8	30.237	72.759
1/8	.3927	.01227	4 5/8	14.529	16.800	9 3/4	30.630	74.662
3/16	.5890	.02761	4 3/4	14.922	17.720	9 7/8	31.023	76.588
1/4	.7854	.04909	4 7/8	13.315	18.665			
5/16	.9817	.07670				10	31.416	78.540
3/8	1.1781	.1104	5	15.708	19.635	10 1/8	31.808	80.515
7/16	1.3744	.1503	5 1/8	16.100	20.629	10 1/4	32.201	82.516
1/2	1.5708	.1963	5 1/4	16.493	21.647	10 3/8	32.594	84.540
9/16	1.7771	.2485	5 3/8	16.886	22.690	10 1/2	32.986	86.590
5/8	1.9635	.3068	5 1/2	17.278	23.758	10 5/8	33.379	88.664
11/16	2.1598	.3712	5 5/8	17.671	24.850	10 3/4	33.772	90.762
3/4	2.3562	.4417	5 3/4	18.064	25.967	10 7/8	34.164	92.885
13/16	2.5525	.5185	5 7/8	18.457	27.108			
7/8	2.7489	.6013				11	34.558	95.033
15/16	2.9452	.6903				11 1/8	34.950	97.205
			6	18.849	28.274	11 1/4	35.343	99.402
1	3.1416	.7854	6 1/8	19.242	29.464	11 3/8	35.735	101.623
1 1/8	3.5343	.9940	6 1/4	19.635	30.679	11 1/2	36.128	103.869
1 1/4	3.9270	1.2271	6 3/8	20.027	31.919	11 5/8	36.521	106.139
1 3/8	4.3197	1.4848	6 1/2	20.420	33.183	11 3/4	36.913	108.434
1 1/2	4.7124	1.7671	6 5/8	20.813	34.471	11 7/8	37.306	110.753
1 5/8	5.1051	2.0739	6 3/4	21.205	35.784			
1 3/4	5.4978	2.4052	6 7/8	21.598	37.122	12	37.699	113.097
1 7/8	5.8905	2.7611				12 1/8	38.091	115.466
			7	21.991	38.484	12 1/4	38.484	117.859
2	6.2832	3.1416	7 1/8	22.383	39.871	12 3/8	38.877	120.276
2 1/8	6.6759	3.5465	7 1/4	22.776	41.282	12 1/2	39.270	122.718
2 1/4	7.0686	3.9760	7 3/8	23.169	42.718	12 5/8	39.662	125.184
2 3/8	7.4613	4.4302	7 1/2	23.562	44.178	12 3/4	40.055	127.676
2 1/2	7.8540	4.9087	7 5/8	23.954	45.663	12 7/8	40.448	130.192
2 5/8	8.2467	5.4119	7 3/4	24.347	47.173			
2 3/4	8.6394	5.9395	7 7/8	24.740	48.707	13	40.840	132.732
2 7/8	9.0321	6.4918				13 1/8	41.233	135.297
			8	25.132	50.265	13 1/4	41.626	137.886
3	9.4248	7.0686	8 1/8	25.515	51.848	13 3/8	42.018	140.500
3 1/8	9.8175	7.6699	8 1/4	25.918	53.456	13 1/2	42.411	143.139
3 1/4	10.210	8.2957	8 3/8	26.310	55.088	13 5/8	42.804	145.802
3 3/8	10.602	8.9462	8 1/2	26.703	56.745	13 3/4	43.197	148.489
3 1/2	10.995	9.6211	8 5/8	27.096	58.426	13 7/8	43.589	151.201
3 5/8	11.388	10.320	8 3/4	27.489	60.132			
3 3/4	11.781	11.044	8 7/8	27.881	61.862	14	43.982	153.938
3 7/8	12.173	11.793				14 1/8	44.375	156.699
			9	28.274	63.617	14 1/4	44.767	159.485
4	12.566	12.566	9 1/8	28.667	65.396	14 3/8	45.160	162.295
4 1/8	12.959	13.364	9 1/4	29.059	67.200	14 1/2	45.553	165.130
4 1/4	13.351	14.186	9 3/8	29.452	69.029	14 5/8	45.945	167.989
4 3/8	13.744	15.033	9 1/2	29.845	70.882	14 3/4	46.338	170.873
						14 7/8	46.731	173.782

WEIGHTS OF IRON AND STEEL

Thickness in Inches	Weight per Square Foot		Thickness in Inches	Weight per Square Foot	
	Iron	Steel		Iron	Steel
1/32	1.263	1.35	11/16	27.79	28.50
1/16	2.526	2.75	3/4	30.31	31.00
3/32	3.789	4.00	13/16	32.84	33.50
1/8	5.052	5.35	7/8	35.37	36.00
5/32	6.315	6.75	15/16	37.89	38.50
3/16	7.578	7.85	1	40.42	41.00
7/32	8.841	9.25	1 1/16	42.50	43.50
1/4	10.10	10.55	1 1/8	45.00	46.00
9/32	11.37	11.75	1 3/16	47.50	48.50
5/16	12.63	13.50	1 1/4	50.00	51.00
11/32	13.89	14.25	1 5/16	52.50	53.50
3/8	15.16	16.00	1 3/8	55.00	56.10
13/32	16.42	16.75	1 7/16	57.50	58.65
7/16	17.68	18.50	1 1/2	60.63	61.20
15/32	18.95	19.25	1 3/4	70.73	71.40
1/2	20.21	21.00	1 7/8	75.00	76.50
9/16	22.73	23.50	2	80.83	81.60
5/8	25.26	26.00	....	.....	.....

WEIGHT OF METALS PER CUBIC INCH

Cast iron.....	.26 pounds	Wrought iron.....	.277 pounds
Steel	.283 pounds	Lead	.410 pounds
Copper	.317 pounds	Brass	.302 pounds

WEIGHT IN POUNDS OF A LINEAL FOOT OF OCTAGON STEEL

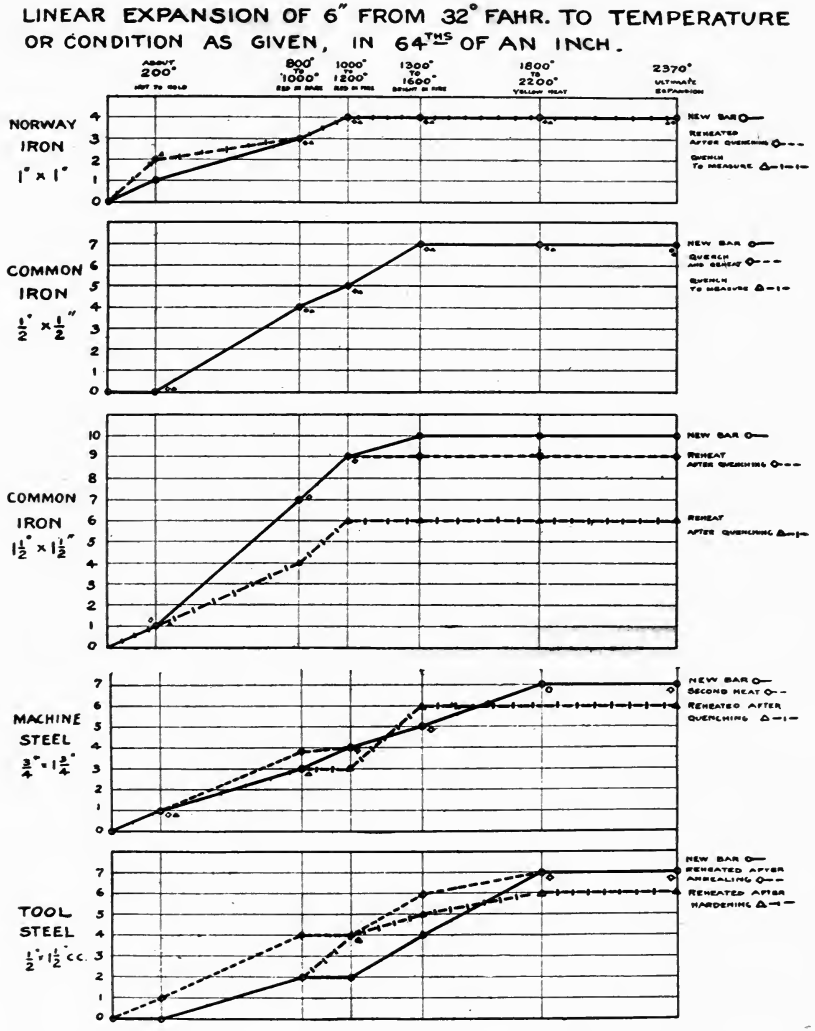
Size in Inches	Octagon	Size in Inches	Octagon	Size in Inches	Octagon
1/16	.011	1 3/8	5.356	3 5/8	37.23
1/8	.044	1 1/2	6.374	3 3/4	39.84
3/16	.099	1 5/8	7.481	3 7/8	42.54
1/4	.177	1 3/4	8.674	4	45.33
5/16	.277	1 7/8	9.960	4 1/4	51.17
3/8	.398	2	11.332	4 1/2	57.37
7/16	.542	2 1/8	12.793	4 3/4	63.92
1/2	.708	2 1/4	14.343	5	70.83
9/16	.896	2 3/8	15.981	5 1/4	78.08
5/8	1.107	2 1/2	17.71	5 1/2	85.70
11/16	1.339	2 5/8	19.52	5 3/4	93.67
3/4	1.594	2 3/4	21.42	6	101.99
13/16	1.870	2 7/8	23.41	7	138.82
7/8	2.169	3	25.50	8	181.32
15/16	2.490	3 1/8	27.66	9	229.48
1	2.833	3 1/4	29.92	10	283.31
1 1/8	3.585	3 3/8	32.27	11	342.80
1 1/4	4.427	3 1/2	34.70	12	407.97

WEIGHTS OF ● AND ■ STEEL PER LINEAL FOOT

(Based on 489.6 lbs. per cubic foot.)

Size Inches	Wt. of ● 1 ft. long	Wt. of ■ 1 ft. long	Size Inches	Wt. of ● 1 ft. long	Wt. of ■ 1 ft. long	Size Inches	Wt. of ● 1 ft. long	Wt. of ■ 1 ft. long
0 1/32	.0026	.0033	3	24.03	30.60	6	96.14	122.4
" 1/16	.0104	.0133	" 1/16	25.04	31.89	" 1/16	98.14	125.0
" 1/8	.0417	.0531	" 1/8	26.08	33.20	" 1/8	100.2	127.6
" 3/16	.0938	.1195	" 3/16	27.13	34.55	" 3/16	102.2	130.2
" 1/4	.1669	.2123	" 1/4	28.20	35.92	" 1/4	104.3	132.8
" 5/16	.2608	.3333	" 5/16	29.30	37.31	" 5/16	106.4	135.5
" 3/8	.3756	.4782	" 3/8	30.42	38.73	" 3/8	108.5	138.2
" 7/16	.5111	.6508	" 7/16	31.56	40.18	" 7/16	110.7	140.9
" 1/2	.6676	.8500	" 1/2	32.71	41.65	" 1/2	112.8	143.6
" 9/16	.8449	1.076	" 9/16	33.90	43.14	" 9/16	114.9	146.5
" 5/8	1.043	1.328	" 5/8	35.09	44.68	" 5/8	117.2	149.2
" 11/16	1.262	1.608	" 11/16	36.31	46.24	" 11/16	119.4	152.1
" 3/4	1.502	1.913	" 3/4	37.56	47.82	" 3/4	121.7	154.9
" 13/16	1.763	2.245	" 13/16	38.81	49.42	" 13/16	123.9	157.8
" 7/8	2.044	2.603	" 7/8	40.10	51.05	" 7/8	126.2	160.8
" 15/16	2.347	2.989	" 15/16	41.40	52.71	" 15/16	128.5	163.6
1	2.670	3.400	4	42.73	54.40	7	130.9	166.6
" 1/16	3.014	3.838	" 1/16	44.07	56.11	" 1/8	135.6	172.6
" 1/8	3.379	4.303	" 1/8	45.44	57.85	" 1/4	140.4	178.7
" 3/16	3.766	4.795	" 3/16	46.83	59.62	" 3/8	145.3	184.9
" 1/4	4.173	5.312	" 1/4	48.24	61.41	" 1/2	150.2	191.3
" 5/16	4.600	5.857	" 5/16	49.66	63.23	" 5/8	155.2	197.7
" 3/8	5.019	6.428	" 3/8	51.11	65.08	" 3/4	160.3	204.2
" 7/16	5.518	7.026	" 7/16	52.58	66.95	" 7/8	165.6	210.8
" 1/2	6.008	7.650	" 1/2	54.07	68.85	8	171.0	217.6
" 9/16	6.520	8.301	" 9/16	55.59	70.78	" 1/8	176.3	224.5
" 5/8	7.051	8.978	" 5/8	57.12	72.73	" 1/4	181.8	231.4
" 11/16	7.604	9.682	" 11/16	58.67	74.70	" 3/8	187.3	238.5
" 3/4	8.178	10.41	" 3/4	60.25	76.71	" 1/2	193.0	245.6
" 13/16	8.773	11.17	" 13/16	61.84	78.74	" 5/8	198.7	252.9
" 7/8	9.388	11.95	" 7/8	63.46	80.81	" 3/4	204.4	260.3
" 15/16	10.02	12.76	" 15/16	65.10	82.89	" 7/8	210.3	267.9
2	10.68	13.60	5	66.76	85.00	9	216.3	275.4
" 1/16	11.36	14.46	" 1/16	68.44	87.14	" 1/8	222.4	283.2
" 1/8	12.06	15.35	" 1/8	70.14	89.30	" 1/4	228.5	290.9
" 3/16	12.78	16.27	" 3/16	71.86	91.49	" 3/8	234.7	298.9
" 1/4	13.52	17.22	" 1/4	73.60	93.72	" 1/2	241.0	306.8
" 5/16	14.28	18.19	" 5/16	75.37	95.96	" 5/8	247.4	315.0
" 3/8	15.07	19.18	" 3/8	77.15	98.23	" 3/4	253.9	323.2
" 7/16	15.86	20.20	" 7/16	78.95	100.5	" 7/8	260.4	331.6
" 1/2	16.69	21.25	" 1/2	80.77	102.8	10	267.0	340.0
" 9/16	17.53	22.33	" 9/16	82.62	105.2	" 1/4	280.6	357.2
" 5/8	18.40	23.43	" 5/8	84.49	107.6	" 1/2	294.4	374.9
" 11/16	19.29	24.56	" 11/16	86.38	110.0	" 3/4	308.6	392.9
" 3/4	20.20	25.00	" 3/4	88.29	112.4	11	323.1	411.4
" 13/16	21.12	26.90	" 13/16	90.22	114.9	" 1/4	337.9	430.3
" 7/8	22.07	28.10	" 7/8	92.17	117.4	" 1/2	353.1	449.6
" 15/16	23.04	29.34	" 15/16	94.14	119.9	" 3/4	368.6	469.4

These figures represent the theoretical weights of *steel*. Iron will run about 2 per cent lighter.


LINEAR EXPANSION OF 6" FROM 32° FAHR. TO TEMPERATURE OR CONDITION AS GIVEN, IN 64THS OF AN INCH.
ABOUT 200°
800° TO 1000°
1000° TO 1200°
1300° TO 1600°
1800° TO 2200°
2370°
NORWAY IRON 1" x 1"
COMMON IRON 1/2" x 1/2"
COMMON IRON 1 1/2" x 1 1/2"
MACHINE STEEL 3/4" x 1 3/4"
TOOL STEEL 1/2" x 1 1/2" cc.
NEW BAR
REHEATED AFTER QUENCHING
QUENCH TO MEASURE
QUENCH AND REHEAT
REHEAT AFTER QUENCHING
SECOND HEAT
REHEATED AFTER QUENCHING
REHEATED AFTER ANNEALING
REHEATED AFTER HARDENING

These curves were plotted from figures procured by measuring ten test bars of each kind and condition.

*WEIGHTS OF FLAT ROLLED STEEL, PER LINEAL FOOT

Thickness Inches	WIDTH—INCHES.										
	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾
1/16	.1060	.1381	.1594	.1859	.212	.2391	.2656	.292	.319	.346	.372
⅛	.2125	.2656	.3188	.3720	.4250	.4782	.5312	.585	.638	.692	.740
3/16	.319	.399	.478	.558	.638	.717	.797	.875	.957	1.04	1.15
¼	.425	.531	.636	.743	.850	.957	1.06	1.17	1.28	1.38	1.49
5/16	.531	.664	.797	.929	1.06	1.20	1.33	1.46	1.59	1.73	1.86
⅜	.638	.797	.957	1.116	1.28	1.43	1.59	1.76	1.92	2.08	2.23
7/16	.744	.929	1.116	1.302	1.49	1.68	1.86	2.05	2.23	2.42	2.60
½	.850	1.06	1.275	1.487	1.70	1.92	2.12	2.34	2.55	2.72	2.98
9/16	.957	1.20	1.434	1.674	1.92	2.15	2.39	2.63	2.87	3.11	3.35
⅝	1.06	1.33	1.594	1.859	2.12	2.39	2.65	2.92	3.19	3.46	3.72
11/16	1.17	1.46	1.753	2.045	2.34	2.63	2.92	3.22	3.51	3.80	4.09
¾	1.28	1.60	1.913	2.232	2.55	2.87	3.19	3.51	3.83	4.15	4.47
13/16	1.38	1.73	2.072	2.417	2.76	3.11	3.45	3.80	4.14	4.49	4.84
⅞	1.49	1.86	2.232	2.604	2.98	3.35	3.72	4.09	4.47	4.84	5.20
15/16	1.60	1.99	2.391	2.789	3.19	3.59	3.99	4.39	4.78	5.18	5.58
1	1.70	2.13	2.55	2.98	3.40	3.83	4.25	4.68	5.10	5.53	5.95
1 1/16	1.81	2.26	2.710	3.161	3.61	4.064	4.52	4.97	5.42	5.87	6.32
1⅛	1.91	2.39	2.868	3.347	3.83	4.304	4.78	5.26	5.74	6.22	6.70
1 3/16	2.02	2.52	3.03	3.533	4.04	4.54	5.05	5.56	6.06	6.56	7.07
1¼	2.12	2.66	3.19	3.72	4.25	4.79	5.31	5.85	6.38	6.91	7.44
1 5/16	2.23	2.79	3.35	3.91	4.46	5.02	5.58	6.14	6.69	7.25	7.81
1⅜	2.34	2.92	3.51	4.09	4.67	5.26	5.84	6.43	7.02	7.60	8.18
1 7/16	2.45	3.06	3.67	4.28	4.89	5.50	6.11	6.72	7.34	7.94	8.56
1½	2.55	3.19	3.83	4.47	5.10	5.74	6.38	7.02	7.65	8.29	8.93
1 9/16	2.66	3.32	3.99	4.65	5.32	5.98	6.64	7.31	7.97	8.74	9.30
1⅝	2.76	3.45	4.15	4.84	5.52	6.22	6.90	7.60	8.29	8.98	9.67
1 11/16	2.87	3.59	4.31	5.02	5.74	6.46	7.17	7.89	8.61	9.33	10.04
1¾	2.98	3.72	4.47	5.21	5.95	6.70	7.44	8.19	8.93	9.67	10.42
1 13/16	3.08	3.85	4.62	5.466	6.16	6.93	7.70	8.48	9.24	10.02	10.79
1⅞	3.19	3.99	4.79	5.58	6.38	7.17	7.97	8.77	9.57	10.36	11.15
1 15/16	3.30	4.12	4.94	5.77	6.59	7.42	8.24	9.06	9.88	10.71	11.53
2	3.40	4.25	5.10	5.95	6.80	7.65	8.50	9.35	10.20	11.05	11.90

*These figures are the theoretical weights, based on 489.6 lbs. per cubic foot of steel. Iron bars will run about 2% lighter.

*WEIGHTS OF FLAT ROLLED STEEL, PER LINEAL FOOT

WIDTH—INCHES.

2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5
.425	.478	.531	.584	.638	.691	.744	.80	.85	.90	.96	1.01	1.06
.850	.96	1.06	1.17	1.28	1.38	1.49	1.59	1.70	1.81	1.91	2.02	2.13
1.28	1.44	1.59	1.75	1.91	2.07	2.23	2.39	2.55	2.71	2.87	3.03	3.19
1.70	1.92	2.12	2.34	2.55	2.76	2.98	3.19	3.40	3.61	3.83	4.04	4.25
2.12	2.39	2.65	2.92	3.19	3.45	3.72	3.99	4.25	4.52	4.78	5.05	5.31
2.55	2.87	3.19	3.51	3.83	4.15	4.47	4.78	5.10	5.42	5.74	6.06	6.38
2.98	3.35	3.72	4.09	4.46	4.83	5.20	5.58	5.95	6.32	6.70	7.07	7.44
3.40	3.83	4.25	4.67	5.10	5.53	5.95	6.38	6.80	7.22	7.65	8.08	8.50
3.83	4.30	4.78	5.26	5.74	6.22	6.70	7.17	7.65	8.13	8.61	9.09	9.57
4.25	4.78	5.31	5.84	6.38	6.91	7.44	7.97	8.50	9.03	9.57	10.10	10.63
4.67	5.26	5.84	6.43	7.02	7.60	8.18	8.76	9.35	9.93	10.52	11.11	11.69
5.10	5.75	6.38	7.02	7.65	8.29	8.93	9.57	10.20	10.84	11.48	12.12	12.75
5.53	6.21	6.90	7.60	8.29	8.98	9.67	10.36	11.05	11.74	12.43	13.12	13.81
5.95	6.69	7.44	8.18	8.93	9.67	10.41	11.16	11.90	12.65	13.39	14.13	14.87
6.38	7.18	7.97	8.77	9.57	10.36	11.16	11.95	12.75	13.55	14.34	15.14	15.94
6.80	7.65	8.50	9.35	10.20	11.05	11.90	12.75	13.60	14.45	15.30	16.15	17.00
7.22	8.13	9.03	9.93	10.84	11.74	12.65	13.55	14.45	15.35	16.26	17.16	18.06
7.65	8.61	9.57	10.52	11.48	12.43	13.39	14.34	15.30	16.26	17.22	18.17	19.13
8.08	9.09	10.10	11.11	12.12	13.12	14.13	15.14	16.15	17.16	18.17	19.18	20.19
8.50	9.57	10.63	11.69	12.75	13.81	14.87	15.94	17.00	18.06	19.13	20.19	21.25
8.93	10.04	11.16	12.27	13.39	14.50	15.62	16.74	17.85	18.96	20.08	21.20	22.32
9.35	10.52	11.69	12.85	14.03	15.20	16.36	17.53	18.70	19.87	21.04	22.21	23.38
9.78	11.00	12.22	13.44	14.66	15.88	17.10	18.33	19.55	20.77	21.99	23.22	24.44
10.20	11.48	12.75	14.03	15.30	16.58	17.85	19.13	20.40	21.68	22.95	24.23	25.50
10.63	11.95	13.28	14.61	15.94	17.27	18.60	19.92	21.25	22.58	23.91	25.24	26.57
11.05	12.43	13.81	15.19	16.58	17.96	19.34	20.72	22.10	23.48	24.87	26.25	27.63
11.47	12.91	14.34	15.78	17.22	18.65	20.08	21.51	22.95	24.38	25.82	27.26	28.69
11.90	13.40	14.88	16.37	17.85	19.34	20.83	22.32	23.80	25.29	26.78	28.27	29.75
12.33	13.86	15.40	16.95	18.49	20.03	21.57	23.11	24.65	26.19	27.73	29.27	30.81
12.75	14.34	15.94	17.53	19.13	20.72	22.31	23.91	25.50	27.10	28.69	30.28	31.87
13.18	14.83	16.47	18.12	19.77	21.41	23.06	24.70	26.35	28.00	29.64	31.29	32.94
13.60	15.30	17.00	18.70	20.40	22.10	23.80	25.50	27.20	28.90	30.60	32.30	34.00

*These figures are the theoretical weights, based on 489.6 lbs. per cubic foot of steel. Iron bars will run about 2% lighter.

HEAT

Sensible heat is said to be that actual, Kinetic, heat energy, capable of transformation into mechanical energy.

Latent heat of expansion is a name for that heat, which is demanded to produce an increase of volume.

The Specific Heat of a body signifies its capacity for heat, or the quantity of heat required, to raise the temperature of the body one degree Fahrenheit, compared with that required to raise the temperature of an equal weight of water one degree.

SPECIFIC HEAT

SUBSTANCE.	SPECIFIC HEAT.	SUBSTANCE.	SPECIFIC HEAT.
Ice	0.504	Anthracite	0.2017
Water at 32° F.	1.000	Oak Wood	0.570
Gaseous Steam	0.475	Fir Wood	0.650
Saturated Steam	0.305	Oxygen (Equal Weights; Constant Volume)	0.1559
Mercury	0.0333	Air (at Constant Pressure)	0.2377
Sulphuric Ether, Density .715	0.5200	Air (Equal Weights Constant Vol.)	0.1688
Alcohol	0.6588	Nitrogen (Equal Wgts.; Constant Volume)	0.1740
Lead	0.0314	Hydrogen (Equal Wgts.; Constant Volume)	2.4096
Gold	0.0324	Carbonic Oxide Equal Weights; Constant Vol.)	0.1768
Tin	0.0566	Carbonic Acid (Equal Weights; Constant Vol.)	0.1714
Silver	0.0570		
Brass	0.0939		
Copper	0.0951		
Zinc	0.0956		
Nickel	0.1086		
Wrought Iron	0.1138 to 0.1255		
Steel	0.1165 to 0.1185		
Cast Iron	0.1298		
Brickwork and Masonry	0.200		
Coal	0.2411		

EXPANSION OF SOLIDS AT ORDINARY TEMPERATURES

D. K. C.

SUBSTANCE	Coefficient for 1° Fahr.	Total Expansion between 32° Fahr. and 212° Fahr.			
		Coefficient		In Length of 10 Feet	
		Decimal	Fraction		
Aluminum (Cast)	.00001234	.002221	1/450	.02221	.2664
Antimony (Crystallized)	.00000627	.001129	1/885	.01129	.1336
Brass (Cast)	.00000957	.001723	1/581	.01723	.2067
Brass (English Plate)	.00001052	.001894	1/529	.01894	.2273
Brass (Sheet)	.00001040	.001872	1/535	.01872	.2246
Brick (Best Stock)	.00000306	.000550	1/1818	.00550	.0660
Brick in Cement Mortar (Headers)	.00000494	.000890	1/1123	.00890	.1068
Brick in Cement Mortar (Stretchers)	.00000256	.000460	1/2174	.00460	.0552
Bronze	.00000975	.001755	1/568	.01755	.2106
Cement (Roman, Dry)	.00000797	.001435	1/694	.01435	.1722
Cement (Portland, Neat)	.00000594	.001070	1/935	.01070	.1284
Cement (Portland, with Sand)	.00000656	.001180	1/847	.01180	.1416
Copper	.00000887	.001596	1/625	.01596	.1915
Glass (Flint)	.00000451	.000812	1/1234	.00812	.0974
Glass (White, Free from Lead)	.00000492	.000886	1/1130	.00886	.1063
Glass (Blown)	.00000498	.000896	1/1111	.00896	.1075
Glass (Thermometer)	.00000499	.000897	1/1111	.00897	.1076
Glass (Hard)	.00000397	.000714	1/1400	.00714	.0857
Granite (Gray, Dry)	.00000438	.000789	1/1266	.00789	.0947
Granite (Red, Dry)	.00000498	.000897	1/1111	.00897	.1076
Gold (Pure)	.00000786	.001415	1/707	.01415	.1698
Iron (Wrought)	.00000648	.001166	1/866	.01166	.1399
Iron (Swedish)	.00000636	.001145	1/873	.01145	.1374
Iron (Cast)	.00000556	.001001	1/1000	.01001	.1201
Iron (Soft)	.00000626	.001126	1/897	.01126	.1351
Lead	.00001571	.002828	1/353	.02828	.3394
Marble (Ordinary, Dry)	.00000363	.000654	1/1530	.00654	.0785
Marble (Ordinary, Moist)	.00000663	.001193	1/838	.01193	.1432
Mercury (Cubic Expansion)	.00009984	.017971	1/56	.17971	2.1565
Nickel	.00000695	.001251	1/800	.01251	.1501
Plaster (White)	.00000922	.001660	1/602	.01660	.1992
Platinum	.00000479	.000863	1/1159	.00863	.1036
Silver (Pure)	.00001079	.001943	1/514	.01943	.2334
Slate	.00000577	.001038	1/967	.01038	.1246
Steel (Cast)	.00000636	.001144	1/874	.01144	.1373
Steel (Tempered)	.00000689	.001240	1/806	.01240	.1488
Stone (Sand, Dry)	.00000652	.001174	1/852	.01174	.1409
Tin	.00001163	.002094	1/477	.02094	.2513
Wood (Pine)	.00000276	.000496	1/2016	.00496	.0595
Zinc	.00001407	.002532	1/395	.02532	.3038
Zinc 8, Tin 1	.00001496	.002692	1/372	.02692	.3230

FOR REFERENCE

Quantities of heat are measured in English units by what is termed the British Thermal Unit, or for brevity B. T. U. The B. T. U. is the quantity of heat required to raise 1 lb. of pure water from a temperature of 62° F. to 63° F.

A heat unit, frequently designated by H. U. in the French or metric system, is termed a Calorie.

The electrical unit of power is the Watt. The mechanical unit of work is the *foot pound,* or the work required to raise one pound, one foot high.

EQUIVALENTS OF POWER AND HEAT

Calorie.		B. T. U.		Ft. Lbs.		Watts.		
0.252	=	1	=	778	=	17.59		
		42.41	=	33000	=	746	=	1 H P.

H. P. or horse power being the unit for large powers.

MELTING POINTS OF METALS—MELTING POINTS OF SOLIDS

Which may be regarded as the freezing points of the corresponding liquids.

	DEGREES FAHR.		DEGREES FAHR.
Aluminum	910	Barium Chloride	2000
Antimony	806	Glass	2377
Bismuth	513	Ice	32
Brass	2860	Iodine	235
Bronze	900	Lard	95
Copper	1012	Nitro-Glycerine	45
Gold, pure	2282	Olive and Linseed oil	—4
Iridium	3542	Phosphorus	111
Iron, cast	2012	Pitch	91
Iron, wrought	2822	Potassium	144
Lead	617	Saltpetre	606
Magnesium	1382	Salt	575
Manganese	2912	Sodium	204
Mercury	—39	Spermaceti	120
Osmium	4532	Stearine	120
Platinum	3272	Sulphur	239
Silver	1832	Tallow	92
Steel	2462	Wax, bees	142
Tin	442		
Zinc	842		

Melting points above 900 are merely approximate.

BOILING POINTS OF VARIOUS SUBSTANCES

At Atmospheric Pressure at Sea Level

	DEGREES FAHR.		DEGREES FAHR.
Alcohol	173	Sulphur	570
Ammonia	140	Sulphuric Acid, s. g. 1.848	590
Benzine	176	Sulphuric Acid, s. g. 1.3	240
Coal Tar	325	Sulphuric ether	100
Linseed Oil	597	Turpentine	315
Mercury	648	Water	212
Naptha	186	Water, Sea	213.2
Nitric Acid, s. g. 1.42	248	Water, Saturated Brine	226
Nitric Acid, s. g. 1.5	210	Wood Spirit	150
Petroleum Rectified	316		

MELTING POINTS OF MIXTURES OR SOLDER

	Degrees Fahr.			Degrees Fahr.	
	Softens at	Melts at		Softens at	Melts at
3 Tin, 2 Lead	348	356	2 Tin, 7 Lead	377½	388
2 Tin, 2 Lead	365	372	2 Tin, 8 Lead	395½	408
2 Tin, 6 Lead	372	383	1 Tin, 1 Zinc	.....	900

CHAPTER V

HOOKS AND CHAINS

We show in this chapter the order in which forging operations should come, and the method of calculating stock for certain things, with a view to leading to a knowledge of how to do many other things not mentioned.

The design of a good hand forged chain hook of small size is the same as for a large hoist hook that must be made with power hammers. The best shape for a hook is that described here, because the wedge-shaped section is the stiffest form for a piece of given weight.

It is our purpose to show how to make hooks and chain links by hand, and the design for large sizes being the same the work of making the heavy ones is done by following the same steps with heavy tools.

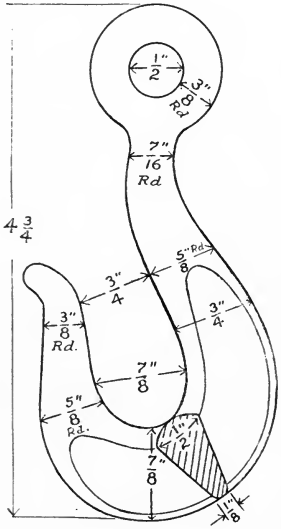


Fig. 1.

Stock of the right dimensions must be selected, and study of the shape and dimensions given in Fig. 1 shows that a flat bar will be nearer the right shape for the heavy section of this hook than a square or round bar would be, and

as the thickest part of the hook is one-half inch, that thickness of flat bar should be selected. As the flat sides must be hammered to make one edge thinner, and the extreme width is seven-eighths of an inch, a bar three-quarters of an inch wide appears to be sufficient. A trial proves this to be the smallest size that will produce a hook of these dimensions without upsetting. So as economy of labor demands that a forging shall be made at the least number of heats and hammer blows possible, ¾″ × ½″ bar stock is selected. The length of a hook is not important, except for convenience in handling after it is on the chain. But if the hook must be just the length given in Fig. 1, a little calculation and good judgment would suggest a piece about five inches long. But experience will prove that it may be one-quarter of an inch shorter, or 4¾″ × ¾″ × ½″ is exactly enough material to make this hook, which is designed for a three-eighths inch chain. If that size and shape of stock is not available, some other size of flat iron, or square or round, may be used. The required length can be found by reference to the table of weights on page 60, where we find that three-quarters by half inch weighs 1.28 lbs. to the foot, and one inch by half inch weighs 1.70 lbs. to the foot, so we have the following proportion: 1.70 lb. is to 1.28 lb. as 4¾ inches is to the required length of 1″×½″ stock, 1.28 times 4.75 equals 6.08; 6.08 divided by 1.70 equals 3.57 or 3 9/16 inches of 1″ × ½″ stock will therefore make the piece. Or in the same manner we find ⅝″ sq., which weighs 1.328 to the foot, would give the proportion, (1.328: 1.28:: 4.75: the unknown length;) 6.08 divided by 1.328 is equal to 4.57. By the table of decimal equivalents, we find that fifty-seven hundredths is nine-sixteenths of an inch, so a piece of ⅝″ sq., 3 9/16″ long would be the same quantity of stock and would be sufficient to make the hook. And as 11/16″ rd. weighs 1.26 lbs., almost the same as ¾ × ½, a piece of round stock 11/16″ in diameter and 4¾″ long would make the same kind of a hook we are going to make out of ¾″ × ½″ × 4¾″.

With a piece of material of the latter dimensions, get a heat about two inches long on one end, and punch a small hole a little farther from the end than it is from either side of the piece. The punch used should be round and not more than one-quarter of an inch on the small end. It should have a straight taper three inches long and be five-eighths

of an inch in diameter at the largest part. If the punch used is too large or has a short, quick taper, it will leave the metal thin on the sides and is apt to split the piece in the end. (See instructions for punching in Chapter 4.)

After the hole is punched, place the piece edgewise, just back of the hole on the bottom fuller, and with the top fuller on the upper edge directly over the bottom fuller as shown in Fig. 2, have a few blows struck with a sledge so as to mark the piece with a depression one-eighth of an inch deep on each edge. If the hole is pinched in, or closed a little by the fullering, no harm will be done, because it can be drifted out again, or will forge out naturally on the horn of the anvil.

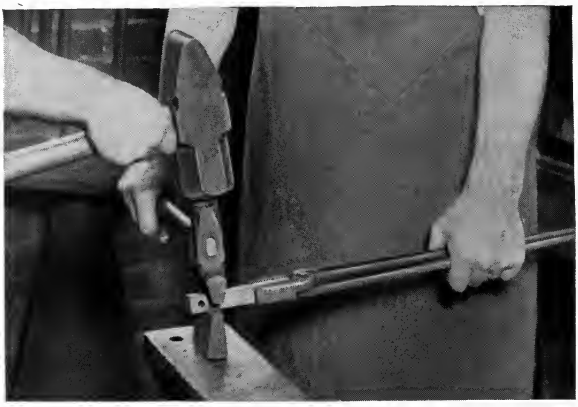


Fig. 2.

For large hooks the neck is fullered and a round boss worked up large enough for the eye before the hole is punched. Some workmen prefer this way for small hooks.

A one and three-quarter pound hammer is best for the size of work shown. The forging is completed with these tools. The shoulder back of the fuller mark should now be hammered down by holding and striking as shown in Fig. 3. This will make a tapered rectangular section, just a trifle over one-half inch square at the smallest part near the hole, and three-quarters by half an inch at the largest part.

Re-heat the piece, put the hole over the point of the horn of the anvil as shown in Fig. 4 and strike the corners and thick parts of the metal around the hole with heavy blows. Keep turning the piece around the horn, strike lightly on the thin places, and reverse the piece so that both sides will be forged out alike. The hole will now be the right size—½″ in diameter—and the metal about it will be ⅜″ round. Now

place the piece on the flat part of the anvil, with the eye part of the hook projecting over the far corner, and forge the

Fig. 3.

tapered rectangular part into tapered round, as large as the piece will make and not more than 1½″ long.

Next, heat the other end of the piece and draw it down to a tapered round ⅜″ in diameter at the end, and otherwise

Fig. 4.

the same size and length as the other round part. Turn a small nib by bending about ¼″ of the small end over the corner of the anvil, and then heat the middle of the piece evenly through all the heavy part; hold it corner up on the face of the anvil and hammer down the corners enough to

make oval edges on this thick part leaving the sides flat about two inches long. Cool the nib end and start the bend over the horn of the anvil, about one-third of the distance from the nib to the eye as shown in Fig. 5. Lay the back of the hook on the anvil face, the eye and back of the piece will then be horizontal on the anvil, while the small end of the hook is almost vertical as seen in Fig. 6. Strike this small end in such a way as to bend it closer to the back of the hook. Done in this manner, the stock will upset somewhat, while, if it is bent over the horn to the desired shape, it would stretch and batter probably making the inside edge of the hook too thin. When it is curved to within one inch of closing, it is time to hammer the bevel on the sides, and should be reheated. Take care all the time to preserve the thickness of the inside by holding at such an angle to the anvil face as will make this middle portion like a wedge with the sides beveled alike.

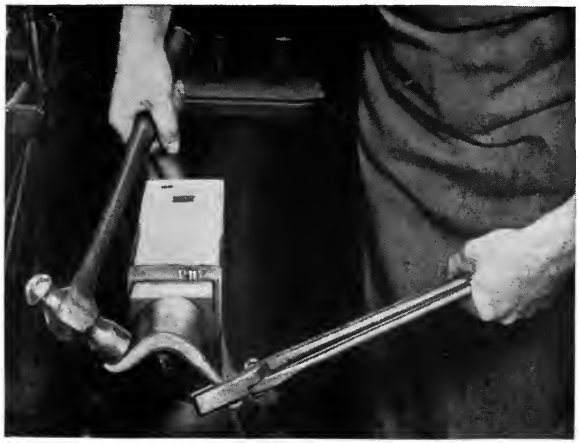


Fig. 5.

Fig. 6.

Holding and hammering this bevel, as shown in Fig. 7, will draw the hook around turning it enough to complete the curve so that the opening is three-quarters of an inch from

Fig. 7.

point to back at the closest place, while the throat is left about one-eighth of an inch wider.

Now heat one inch of the stem under the eye, dip the eye in water about half way to cool it, so a hammer blow will not knock it out of round. Rest the stem, back down, on the point of the anvil horn, and strike the eye to curve it back out of the way in loading the hook. An experienced man can make a chain hook of this kind in five heats, and it can be done in twenty minutes, but for good, smooth work, six heats and thirty minutes' time is a better allowance.

GRAB HOOKS

A grab hook is just wide enough open to admit the diameter of the chain link. They are easily made of square stock. Figure 8 shows two of them made of ¾″ × ¾″ × 7½″ the right size of stock for a ⅜″ chain according to the empirical formula on page 75, which accords with good shop practice and has been verified by laboratory tests to prove the formula. After the eye of this hook is forged it may be bent toward either corner. When bent with the eye hole at a right angle with the hook point and used to catch over a link above after the chain is wrapped around a load, the link in the eye of the hook pulls more torsion than it would

if the hook was bent so the point came in the same direction as the eye hole, like it does in the left hand picture. This style of hook is therefore preferable for a large class of work. These hooks can be forged on the anvil with no other tools than a hammer and punch. A careful workman will make them as smooth and free from tool marks as these pictures, by making the eye after slightly flattening two opposite side corners for one inch at the end then punching the hole and rounding the eye as shown in Fig. 4, and described for the chain hook, after this is done the bend is started as in Fig. 5. But to finish bending, the back of the hook must not rest on the flat of the anvil but in a right angle corner, or the outside corner of the square that is to

Fig. 8.

become the outer edge of the hook will be flattened. By holding the partly bent hook on the table against the end of the anvil face with the hook point projecting upward at an angle of forty-five degrees and striking on the end of the outside corner the bend can be completed and the hook closed to within 1/16″ of the link diameter, the hammer marks and the flat place made on the outside corner near the end can now be removed by drawing a slight taper with four flat sides which improves the appearance of the hook.

GATE HOOK

This hook is shown to illustrate how to forge a shoulder and twist square iron for the purpose of ornamentation. In Fig. 9 the square bar is held with one corner turned up, the hammer will land on the piece where it touches the corner of the anvil then the other corner of the square will be turned up, by hammering only the part that is over the anvil it is made round and the anvil corner forms the shoulder which marks the square part of the piece from the round, then the hook eye is bent out of this round part and a similar round part is forged on the other end of the piece and the hook bent to its proper curve.

Fig. 9.

To twist it the piece is made red hot in the middle, the cold ends of the square part can be held in tongs as shown in Fig. 10, and twisted one full turn. This makes all corners show on each side in the part that was red hot when the twisting was done and is a neat ornamental piece of work.

Fig. 10.

Heavy bars should have one end fastened in a vise while a wrench is used on the other end for twisting. Wrought iron should be an even red heat in the part to be twisted and cooled in water if necessary up to the place where the twist should end, for red hot iron gripped tightly in vise or tongs will be compressed and the corner of the hot metal that is crowded against the corner of the jaw of the vise or tongs will be nicked and present a broken line in the curve marring its beauty.

EFFECT OF HEAT

Irregular curves and twisting will occur at uneven or high heats. It is a curious fact that iron heated above redness does not always bend or twist as easily as it does at a fair red. At a high yellow or white heat a square bar may be held at one end while the other is twisted and sometimes no effect of the twisting will appear on the corners of the square in that part which was the hottest though an irregular and uneven twisted effect will appear in those parts of the bar that were not too hot. This is particularly true of Swedes iron. But the exact shade of color that is best for bending or twisting common wrought iron cannot be known without trial on a piece of the same composition. Owing to the varying amounts of sulphur and phosphorus in it some iron will bend or twist easily and safely at a low red heat while other pieces that are high in those impurities break with the same treatment. Wrought iron made of Swedish ore is uniform and dependable because it has very little of any other element in it. The chemical composition of steel also is usually more definitely fixed than common wrought iron, and the proper working heats for Swede's iron or steel can be more accurately stated. Intelligent workmen easily learn to vary the heat according to the quality of the material and the kind of work to be done on it. A fair red heat is always right for bending or twisting Swedes iron or steel.

The formula given here is intended to help those who know how to make hooks, to select the proper size and shape of stock for making them to suit any ordinary chain used for common purposes.

FORMULA

Empirical formula to determine the right size of stock for hand-forged *Hooks* to suit any round link stock.

l.d. is for link diameter.
D.H. is for diameter of hook stock.
L.H.S. is for length of hook stock.

Grab Hook to pull full load that the chain will stand { 2 x l. d.=D. H. Sq.
10 x D. H.=L. H. S.

Hoist Hook to pull full load that the chain will stand { 2½ x l. d.=D. H. Rd.
7 x D. H.=L. H. S.

Chain Hook to pull half the load the chain will stand { 2 x l. d.=D. H. Rd.
6 x D. H.=L. H. S.

2, 2½, 6, 7, and 10 are the constants for any size of chain made of round stock.

Example for grab hook, on chain made of ⅝″ round stock: $2 \times \frac{5}{8}'' = 1\frac{1}{4}''$, $10 \times 1\frac{1}{4}'' = 12\frac{1}{2}''$, a piece of square material $1\frac{1}{4}''$ in diameter, $12\frac{1}{2}''$ long should be used.

Example for hoist hook, on chain made of ½″ round stock: $2\frac{1}{2}'' \times \frac{1}{2}'' = 1\frac{1}{4}''$, $7 \times 1\frac{1}{4}'' = 8\frac{3}{4}''$, a piece of round material $1\frac{1}{4}''$ in diameter $8\frac{3}{4}''$ long should be used.

CHAIN MAKING

To make a chain link, a piece of stock the right length must first be cut. If the link is of the size and shape used in the tests given in our table of tests, the calculation would be as follows: Link 2″ long, ⅞″ wide inside measure, two ⅞″ half circles make up the ends, leaving two straight sides each $1\frac{1}{8}''$ long. As two ⅞″ half circles equal one complete ring of ⅞″ inside diameter, we must add the thickness of the stock to that diameter, and multiply by 3.1416 or 3 1/7, which is the figure most commonly used in forge work; ⅞″ plus ⅜″ equals $1\frac{1}{4}''$; $1\frac{1}{4} \times 3$ 1/7 equals 3.93, or practically 4″ of stock required for the two ends; $1\frac{1}{8}''$ plus $1\frac{1}{8}''$ plus 4″ equals $6\frac{1}{4}''$, the length of stock needed for the link. This should be heated in the middle, and bent into a U shape, then the inside corner of each end should be scarfed on opposite sides as in Fig. 11, bent in and lapped for welding, one end on top of the other when the link lies flat on the anvil, as seen in Fig. 12, after which it is rounded and forged smooth on the horn. Turning

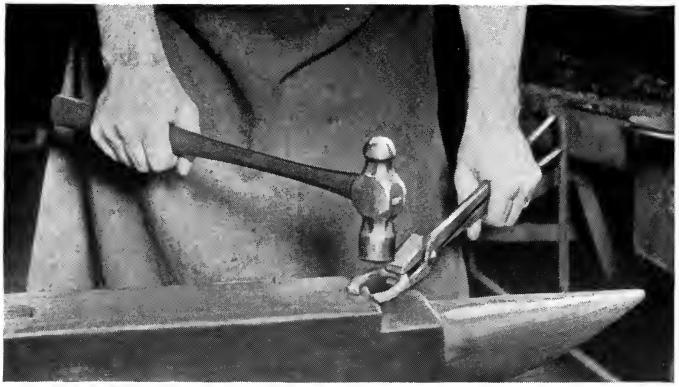


Fig. 11.

Fig. 12.

Fig. 13.

first one side and then the other to the position shown in Fig. 13.

In a chain factory small links are bent in power machines which coil long bars into oblong rings, that are afterward cut off at an angle through the metal. This sheared angle forms scarf enough for welding. Thus the chain maker of small sizes takes only one heat for each link, laps it and completes the weld also at this heat. But the best of chain, and all large links, such as short, thick anchor and hoist chains, are made of iron handled in the manner described. A smith and three or four helpers, working together, heat and bend, then heat and scarf with a top fuller and finally heat and weld each link carefully.

Standard chain links are not proportioned as the samples shown here, but are shorter and narrower. They should measure inside as wide as the diameter of the stock plus one-sixteenth of an inch, and be three times the diameter of the stock in length.

The tests tabulated on the next page are of actual results, given in such a way that it is hoped they can be well understood by those who have made no previous study of such subjects.

A large number of American iron links and many Swedes iron and other chain hooks were tested. All were forged by the same workman, carefully hammered to exact dimensions, given in preceding pages the heat treatment being the same on each piece of the same kind of stock.

SOME LESSONS TO BE LEARNED FROM THE TESTS

It will be seen by an examination of the tests given for hooks, links and rounds, that a hook of this design is well adapted for three-eighths inch chain, and that with chain wrapped around the load and fastened in the ordinary manner, 4,000 pounds, or two tons, could be lifted. But this should not be considered as a "safe load" in the usual meaning of that term, as repeated stresses of that weight would cause failure, or probably a long continued load of one ton in the hook, or two tons in the chain would result in failure somewhere, some time.

The object we have in giving the result of these tests in this manner is to show actual results and let our readers judge for themselves.

In order to determine the best kind of material for small hooks and chains, the following tests have been made on a large number of pieces. The hand made hooks were all of the same pattern and dimensions, and all specimens of like material were treated in the same manner.

CHAIN LINK TESTS

Material tested.	Load lifted without sign of failure.		Light overload with slight failure.		Heavy overload causing destruction.		Effect on piece.	
	Max. lbs.	Min. lbs.	Max. lbs.	Min. lbs.	Max. lbs.	Min. lbs.	Max.	Min.
⅜" rd. common iron links.....	4200	4000	5000	5000	10000	5200	Broke in end not welded.	Broke in end welded.

HOOK TESTS

Hand forged Bessemer or machine steel chain hooks	4440	3000	6430	4000	7440	7260	Snapped off.	Half broken.
Hand forged Norway or Swedes iron chain hooks	2085	2000	2275	2090	4800	4000	Pulled open without crack.	
Hand forged horseshoe bar or refined iron chain hooks.....	2500	2250	3000	2500	5230	4070	Half broken and twisted.	
Soft steel drop forged hoist hooks....	2300	1960	3440	2360	4120	3920	Pulled open without crack.	

SPECIMEN STOCK TESTS

Material tested.	Load lifted without sign of failure.		Light overload with slight failure.		Heavy overload causing destruction.		Effect on piece. Elongation per in.	
	Max. lbs.	Min. lbs.	Max. lbs.	Min. lbs.	Max. lbs.	Min. lbs.	Max.	Min.
⅜″ rd., 1″ long, Swedes iron	4000	3800	4200	4000	4800	4700	.57″	.55″
⅜″ rd., 1″ long, H. S. B. or refined iron	6000	5700	6100	5800	6670	5870	.38″	.25″
⅜″ rd., 1″ long, Soft steel	6000	5600	6400	5800	9670	8100	.30″	.30″
Common iron file finished to size, ⅜″ rd., 1″ long	5000	5000	5300	5150	5640	5600	.38″	.33″
Common iron commercial bar, as it came from store, ⅜″ rd	3800	3800	4000	3900	5970	5460	.33″	.30″

For the specimen stock tests, the ⅜ inch round pieces, 1 inch long were turned down from ½ inch stock and file finished in a lathe, the heavy ends were gripped so that the load pulled straight lengthwise; the ⅜ inch round, common iron commercial bar was gripped on 5 inches of each end so that 4 inches of it were affected by the pull, while, of course, only 1 inch of the other specimens was affected.

One of the interesting things observed in these tests is the great uniformity of Swedes iron in every case. This is indicated by the comparatively small difference in the maximum and minimum figures through a larger number of tests for hooks, and the larger difference in the figures for refined iron and steel hooks. In fact, no Swedes iron hook was pulled open one-sixty-fourth of an inch by a one-ton load, but an increase of so small an amount as eighty-five pounds in one case and less than one hundred pounds in several cases, caused them to open, and stay open, this short distance.

One refined iron hook was sprung back to its original shape when the load was taken off, and did not take its permanent set until it had been pulled open one thirty-second of an inch by a load of three thousand pounds. The steel hooks had still greater springiness. Though one of them opened one sixty-fourth at one thousand pounds, it required a load of four thousand four hundred and forty to open another the same distance. One took a permanent set when one-sixteenth of an inch open with a load of four thousand pounds, while the other did not remain open until it had been successively loaded and opened, as follows: 4,600 lbs. 1/32″ open; 5,400 lbs. 1/16″ open; 5,730 lbs. ⅛″ open; at 6,430 lbs. ¼″ open, then it remained 1/16″ open, when the load was taken off. When a load of seven thousand one hundred pounds was applied, it began to fail rapidly, and when the load was increased one hundred and sixty pounds more, it snapped off.

There was no difference in the heat treatment. In fact, no attempt at heat treatment for the steel pieces, except to forge them and allow them to cool afterward in air. All the specimens were in their natural condition, so the variableness of steel, and the uniform reliability of Swedes iron is well shown in these tests.

Of the links broken for this test, some were rough welds, made with only ten hammer blows — two on each side and six on the end. These always broke in the welded end, but showed a clean break almost square across the weld, often leaving the point of the scarf welded to each opposite side. In some cases the break was at the tip end of the lap, but we found no portion of the weld torn loose in any of these fractures, though none of them broke with a load of less than five thousand two hundred pounds, all of the rough welds being near that figure.

The smooth, well finished welds that had been reheated and forged as neatly as possible, always gave the higher tests. Only a few links bore the maximum load of ten thousand pounds, and broke in the unwelded end as several others did at a lesser load. These fractures were not such square, clean breaks nor so coarse grained as the others, but were torn, with roughened points instead of grains showing on the broken end. Sometimes when the fracture was in the welded end, it had followed the line of welding, but as the pull required to cause such fracture was about the same as that which sometimes pulled a link apart elsewhere, this did not refute the evidence in favor of well working welds at good heats with a hammer.

The three-eighths round pieces that were pulled in two, show what might be expected of the different qualities. Swedes iron stretched enormously, and necked down to nearly one-eighth of an inch in diameter at the middle of the piece before it broke, while the American refined iron necked down to less than one-quarter inch, and the common iron to nearly one-quarter inch before breaking.

If we consider strength and reliability only, omitting the factors of possible stiffness and wear, it would seem that Swedes iron for hooks, and common iron for chain, is the safest and best material.

The slight difference in heat treatment likely to occur at the forge of a good workman makes no appreciable difference in the properties of Swedes iron, and welds that are as good as the rest of the piece are not at all difficult to make with common iron, while the reverse is true of the other kinds of material used for forgings. A chain or hook is no stronger than its weakest part, is a truism that needs no argument.

PART TWO

Part Two treats of welding iron and steel, with instructions for preserving the strength of the materials

CHAPTER VI

WELDING

WHAT A WELD IS

The short definition of the verb weld according to Webster's dictionary is, "To press or beat into intimate or permanent union."

The New Century dictionary defines the noun "weld" as "a solid union of metallic pieces formed by welding; a welded junction or joint."

"To unite or consolidate pieces of metal or metallic powder, by hammering or compression with or without previous softening by heat."

For the learner, however, a careful study of the following is recommended as containing the substance of what ought to be said on the subject.

"Welding is and has long been a matter of great practical importance, chiefly in the manufacture of iron and steel and of the various tools, utensils and implements made of those metals. Iron has the valuable property of continuing in a kind of pasty condition through quite a wide range of temperature below its melting point, and this is a circumstance highly favorable to the process of welding. Most metals, however, pass quickly, when sufficiently heated, from a solid to a liquid condition, and with such welding is more difficult. The term "welding" is more generally used when the junction of the pieces is effected without the actual fusing-point of the metal having been reached. Sheets of lead have sometimes been united together by fusing the metal with a blow pipe along the two edges in contact with each other, and this has been called autogenous soldering, or burning, if the heating was done with a hot iron. Still, "the difference between welding and autogenous soldering is only one of degree."—(Percy).

"The term welding is also used in speaking of the uniting of articles not metallic. Most metals when in the form of powder can be consolidated or welded into a perfectly homogenous mass by sufficient pressure without the aid of heat.

The same is true of various non-metallic substances, such as graphite, coal, and probably many others."

OTHER METALS

Welding should be thought of as a true metallic union between pieces of like material caused by heating and hammering. This in its simplest form is done with puddled or wrought iron, but low carbon steel can be welded almost as well. High carbon tool-steel can not be welded successfully by hammering, because it falls so suddenly from a hard state to a fluid at high heats.

Tool-steel of 80-point carbon, which is good for cold chisels and similar tools, can be welded solidly to iron but not to steel of the same kind.

Copper can be welded to iron at the forge, but its use in this manner is of no practical value.

USE OF FLUXES

A flux is used for converting the oxide into a fluid at a lower temperature than would make it a liquid without a flux. The oxide of a metal must be thin enough to splash off or be swept from the surfaces to be put in contact for the weld, or metallic union can not take place. Borax sprinkled on iron or steel that is at a high yellow heat will cause the thick, slimy, sticky oxide which covers it to become so fluid that it will drip or splash off when the piece is struck. As the oxide forms a scale when it is cold, any of it remaining between the surfaces that were placed in contact will prevent perfect welding of the pieces. So, for pieces which would be injured by a heat high enough to make its oxide liquid, this flux should be used.

Sand, dolomite, pulverized marble or glass when used for a flux are valuable principally for the fact that their particles clinging to the thin edges of the piece to be welded, prevent them from being burned while the thicker parts are being heated. If borax is mixed with them the chemical action is obtained also.

KINDS OF WELDS

A few simple welded joints and the way to handle them are the only illustrations that will be used in this book. These are fundamental and should be learned before attempt-

ing to make other forms of welded joints which are more difficult to handle.

Butt Welding

A butt weld is made by joining two pieces end to end. It is most frequently done with round or square pieces several feet long and not less than three-quarters of an inch in diameter; smaller sizes lose the heat quickly and bend so easily that butt welding them is more difficult than with stock over three-quarters of an inch in diameter.

To butt weld two long bars is a two man job. Hammer the corners of the ends back so the centers will touch first, then heat for welding and place them end to end; while in that position strike endwise on the cold end of one bar while the other is held rigidly enough to receive the shock of the hammer blow; this upsets the hot part and it should be hammered on the sides enough to reduce it to the right diameter and complete the work.

Jump Welding

A jump weld is joining the end of one piece to the side of another, in a manner similar to butt welding.

V, or Split Welding

If the end of a piece is split in the center, and opened to receive the side of another piece, it is called a split weld. This is an excellent way to join steel to iron, endwise; the iron piece should be split and opened in the form of a V and the steel scarfed like a wedge to fit the V; they can be put together before heating to weld and then heated and hammered endwise and on the sides, making a solid joint. Sometimes the end of both pieces is split and opened like a V and the two clefts crossed and pushed into each other where they are closed on the pieces, locking them into position for welding. This form of split or cleft welding is often practiced with steel that is difficult to join by simple lap welds.

Lap Welding

Two pieces that have been upset and scarfed are shown in Fig. 1, held in position ready for welding. The piece held by the left hand is on top of the other so the tongs in the right hand can be dropped without disturbing the position of the piece, and the hammer which is ready at hand can

be caught quickly to strike the blows that will cause the plastic metal to flow into that intimate union called a weld. The face of the scarf should be 1½ times as long as the thickness

Fig. 1.

of the piece. This fixes the length, and the angle of the lap is less than 45°. The thin point of the scarf cools more quickly than the thick heel, so the point of the under piece is not touching the cold anvil. Metal conducts heat about four hundred times as fast as air, and the experienced smith has learned to avoid as far as possible the chilling effect of slow hammer blows or lingering contact of the hot material with other tools.

T. Weld

Another lap or scarf weld is shown in Fig. 2. This is called a T weld. If the material of which it is made was diffi-

Fig. 2.

cult to weld, the piece held in the left hand could have been split and opened so the other piece would lie in the V. Then with contact on two sides, a more solid joint might be produced, or if the piece held by the right hand was larger and

the material easy to weld it would be simpler to make end contact only with the left hand piece, and hold it vertical while it was struck with the hammer on the cold end, making a jump weld.

Corner Welding

The lap weld corner is stiffer than a bent corner. Rocker plates for the crooked framed sills of wood for agricultural machines, cars, wagons, carriages and the like are better if the iron fiber is crossed by such a lap and scarf weld, as is shown in Fig. 3.

When the corner is to be finished more or less than a right angle the scarf and lap should be made accordingly. When tensile strength only is required of a weld, care should be taken to keep the fiber of the stock parallel with the direction of strain. But if transverse stress will be applied to a weld

Fig. 3.

the crossed fiber which adds to the rigidity of the piece is permitted.

This does not apply to steel forging as emphatically as it does to wrought iron.

A fillet welded inside, or a "dutchman" welded on the outside, to build up a forged corner stiffens more and is often a more economical way to finish such pieces than with stock all of one piece, which makes the so-called solid forging.

FAGOT, OR PILE WELDING

A good opportunity to study welding conditions is given in Fig. 4. Only that portion of the piece which is seen in the pile or fagot on the anvil is to be welded. The rest of

the bar serves as a handle or porter bar that is cut off after the weld is made and the forging is finished. As the piece is of

Fig. 4.

good size and convenient to hold it is not difficult to study the conditions that must be controlled while working with this piece.

There are only three things to be learned about this work, —

The proper heat condition must be produced in the piece. It must then be placed and kept in *the right position.* Then it must *be properly hammered.*

Allowance to Weld On

In Fig. 5 the size of the top and bottom swages is shown

Fig. 5.

to be ¾", and the width of the bar is seen to be the same as the diameter of the round that is being finished in the swage, the thickness of the bar is just half its width or ⅜". Now it should be observed that the pile for the weld in Fig. 4 is three times ⅜".

Therefore the allowance to weld on is one-half of the diameter of the finished forging; this allowance is not all for loss. In fact, one half of this extra piece is not usually lost in the welding heats taken by experienced workmen, but in this as in many welded joints it is best to have that much allowance to weld on, so the piece will be of the right thickness after the hammering necessary to make the weld has been done.

Heating to Weld

Put the piece in a clean bright fire and guard against excessive oxidation by keeping plenty of coke burning around it. The depth of burning coke under the piece should be five inches, and the fire should not be over four inches wide. On top of the piece three inches of burning coke should be piled; it is then in the midst of the fire at the hottest place.

Oxidation

The oxidation that is a source of trouble when excessive, will serve as an indication of the welding heat, for the metal is sticky when its oxide ceases to be so under the influence of heat. The oxide that covers the piece that is heated to 1600 degrees Fahr. is plastic and sticky, and remains in this condition until the metal is made several hundred degrees hotter, so it can not be expelled from the joint by the shock of the hammer blows, without using a flux. It can be scraped off of the piece, but a new coat is formed so quickly that much of it would remain in the joint, causing serious defects in the weld; but wrought iron will stand heat considerably higher, so the temperature should be raised to the degree that makes the oxide a fluid so thin that it will splash when quick hammer blows strike it hard enough to make the metal flow, in the joint. If no impurity from the fuel is allowed to remain in the joint and the weld is treated in this manner, it will be as strong as the material in which it is made, if the "fixing" mentioned in Chapter 3 is right.

Strength of Welded Joints

The imperfections and corresponding loss of strength in welded joints is of more consequence in lap welds like Fig. 1. It is very difficult to determine what allowance ought to be made for loss in the tensile strength of welded rods or bars, but some conclusions may be drawn from the chain link tests given in Chapter 5, where it will be seen that some of the welded joints of the links were stronger than the rod of which they were made.

Hammering a Weld

The first blow should land over the middle of the joint as shown in Fig. 4. This allows the oxide to escape from the end of the joint as well as the sides. Rapid hammer blows should be delivered until the entire length of the joint has been covered by them, then the piece should be turned bottom side up and hammered an equal amount. Next the other two sides or edges of the joint must be hammered equally, and the welding is complete.

Forging the Weld

Fig. 6 shows the use of a top and bottom fuller to make depressions in the corners of the square forging to mark the place where another shape begins. Then after the corners of the square from the middle of the fuller marks to the end of the piece are hammered down and this part of the piece is partly rounded as it is held on the flat face of the anvil and struck with the hammer, it may be finished true to size and shape in the swages, holding it in the position

Fig. 6.

shown in Fig. 5, and turning slightly between the blows of the sledge.

A Reason for Welding

Fig. 7 shows the finished forging, and it illustrates how

Fig. 7.

large forgings may be made out of small pieces of stock by fagoting, or pile welding.

When this amount of thermal and physical treatment has been correctly given to a weld of this size the metal is in as good or better condition than the material of which it was made. It is the way common wrought iron is changed into refined wrought iron.

It is not difficult to learn to do correctly any one of the three essentials for good work. But getting the time and manner of "proper heat," "right position," and "good hammering," correct for all sizes and kinds of material, requires much study and practice.

WELDING RINGS ON SHAFTS

A piece of square or round stock bent into a ring to fit a shaft, can be solidly welded into place. When it is some distance from both ends of the shaft it is called a collar, and

Fig. 8.

if it is flush on the end of a round shaft as shown in Fig. 8, it is a head and the piece can be used for a bolt.

Weld Head Bolts

Bolts headed in this way are not recognized as standard and an authorized size for the heads can not be given. It is customary to make them larger than the standard for bolt heads given in Chapter 4. Rings made of square stock one-fourth less than the diameter of the shaft should be bent to fit the shaft as shown in Fig. 8, the ends of the ring separated 1/16″.

To Get the Welding Heat

The shaft should be heated first to a yellow color, then the ring be put in place and both pieces raised to the white welding heat. It must then be placed in the position and the first hammer blow landed, as shown in the picture, on that quarter, to close the space between the ends of the ring, and weld it to the shaft at the same time. The next hammer blow must land on the quarter nearest the other end of the ring. This welds the ends of the ring together and the bolt head can now be forged to the size and shape desired.

EYE BOLT WELD

Work of this kind should be done as shown in the illustrations, after the end of the piece is pointed or scarfed, and the two shoulders or sharp bends made as shown in Fig. 9. That portion of stock between the shoulders is bent into a ring forming the eye, while the scarfed end lies on the bar and the shoulders meet as seen in Fig. 10, where the piece is at welding heat and in posi-

Fig. 9.

tion for the first hammer blow. It is important for the strength and symmetry of this forging that the welded joint should be kept central, the side that is uppermost gets the most effect of the hammer blows, and the metal flows away from them, so before the welding heat is lost the piece must be turned half over so the other side may be hammered enough to keep the weld joint on the median line.

Fig. 10.

RING WELDING

Fig. 11 shows a ring in the finished eyebolt or cockeye, ready for welding. The tip or point of the scarf on the

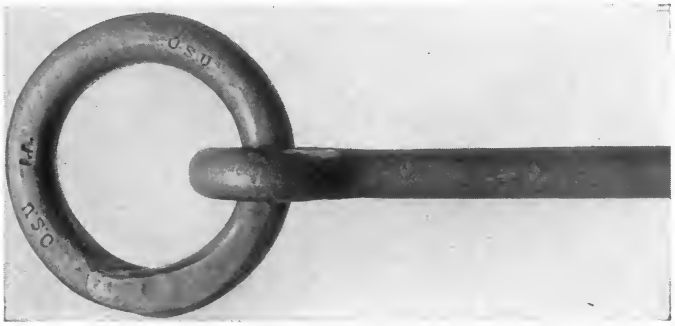


Fig. 11.

ring is lapped over until it rests on the heel or thickest part of the scarf of the other side, these points should be blunt, or rounded, not thin and sharp, or they will lose heat so quickly that they will not be welded when the piece is hammered down to size. The point of the scarf for lap welding

should always have enough body to hold the heat until it is hammered enough to make the weld.

A good way to hold small pieces for making scarfs ready to lap for welding, is on a corner of the anvil as shown with a link in Fig. 12. The hammering to weld, should begin at the position shown in Fig. 13, and the piece rounded as in Fig. 14.

Fig. 12.

Fig. 13.

Fig. 14.

CHAPTER VII

SPECIAL WELDS: STRENGTH AND COST OF WORK

THE SWIVEL

To make a swivel, such as is shown in Fig. 1, a piece of round stock is upset and scarfed on the ends, then bent to a U shape and the scarfed ends welded on opposite sides of a nut. Then a bolt is forged with a round head and a stem about half the size is drawn down on the other end. After putting the bolt through the hole in the nut, the stem is bent into a ring and the free end of it welded to the shoulder of the bolt.

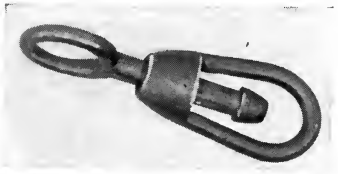


Fig. 1.

THE ROPE HOOK

A hook with an eye that has been drawn down to a smaller size than the bar, bent into a ring, and welded where the end laps on the bar similar to the cockeye shown in Fig. 9, Chapter VI, can be easily and quickly made of round stock and is good for a rope or light chain hook. See Fig. 2.

Fig. 2.

TURN BUCKLE

Six scarf and lap welds are required in the piece shown in Fig. 3. The two nuts are made by bending rings of rectangular stock and lap welding the ends, then the side bars are welded on to opposite sides of the nuts; the welds in the rings should be covered with the lap of the bars. Made in this way the fiber of the material runs in the direction of the greatest strain in service.

Fig. 3.

SOCKET WRENCH

This piece, Fig. 4, has three welds in it. The handle is best welded to the stem by the cleft weld method, the stem being split to sufficient depth to allow the open ends of the V to lap one-third around the handle on each side. A welded ring made of flat stock is driven part way on the other end of the stem, and after welding it in place, the socket can be formed to fit any shape of nut desired.

Where power machines are used for forging, this socket can be made more cheaply by the extrusion or squirting method in dies, such as are shown in the illustration of special tools in Chapter II., Fig. 21. For this method a piece of stock the same diameter, but some longer than the socket part outside, is put in the die and the punch forced into it forming the socket and flowing the metal of the hole to form the stem.

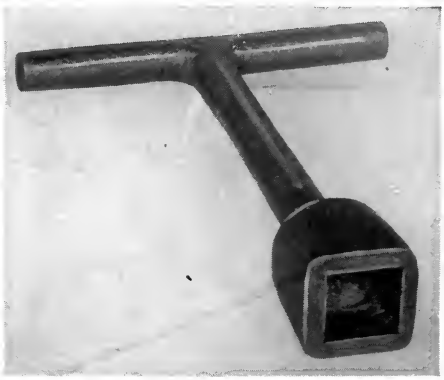


Fig. 4.

LARGE SHANK WELD

Fig. 5 represents a piece of work about the *limit of sizes* that can be made in ordinary forge fires; the stem of one inch square iron was welded to the ¾″ x 4″ by the jump welding method. Two fires are used for heating the separate pieces. Special care must be taken at this work to remove the dross and cinder from the flat piece before the

Fig. 5.

stem is placed for welding, and the center of the weld must unite first or the oxide will remain in the joint, weakening it greatly. When properly done, a tool shank, such as is shown here, can not be torn out at the weld, as the 1″ x 1″ will break easier than the joint.

FOR ORNAMENTS

Bundles of rods bound with wire can be welded at the ends, for useful purposes. In Fig. 6 are two bundles so

Fig. 6.

welded to be used in ornamental designs. Two bundles of two rods each were welded at both ends and twisted to the right, clockwise. After that the two pairs of twisted rods were made into one bundle welded at both ends, and twisted to the left, counter clockwise, giving the tangled effect shown in the illustration.

Many other designs can be worked out in this manner. One of the most interesting, being balls of basket work with metal ornaments inside, seen through the meshes. To make this, a larger number of rods, bundled together with the metal ornaments in their midst, are welded at both ends, and then separated along the middle by curving each rod outward to form the ball or oval that may be called for. It is not necessary to give further illustration or instruction on this phase of the subject, for whoever has made the pieces that have been described is prepared to invent and make many other welded forms.

WELDING STEEL TO IRON

Excellent tools are made with bases of material that

will not harden, having material with hardening properties welded to the faces that require it. Fig. 7 shows such a tool

Fig. 7.

being made. The base has been forged of wrought iron, the stub end, which is held by the tongs, is scarfed ready for welding to the piece that will serve for the handle which will be ⅞″ round iron, 14″ long. In the illustration, the disc of crucible steel that is partly cut from the bar, in the right hand of the smith, is being welded by the blows of the six-pound hammer held by the helper. When heating for this weld, the large piece should be made the hottest.

USING A FLUX

When both pieces in Fig. 7 are yellow hot, borax or welding flux is put on the surfaces that are to come in contact for the weld, then the iron is made white hot, and the steel a bright yellow. The borax liquifies the oxide and is splashed off with it, or if the surface is large it may be swept off with a broom the instant before the pieces are put in contact.

DANGER OF NOT GETTING FLUX OUT OF WELD

Any borax or welding flux that remains in the joint weakens it. Usually the contact of pieces can be made in such a way that it is squeezed out of the joint as the welding proceeds. If this can not be done, it must be quickly swept off before contact is made for the weld, because any imperfection in the weld for this kind of tool would permit the thin, hard face of it to break, which it will not do when solidly welded to the unhardened back or bottom part.

USE FOR STEEL TO IRON WELD

As seen in Fig. 8, this forging is completed for a *bolt heading tool.* After the hole is drilled, the face of the top of

Fig. 8.

the tool is hardened by heating and quenching, as is fully explained in Part III of this book. The bottom or iron portion will not harden or become brittle or springy.

LIGHT FORGING

All the pieces illustrated in this book are classed as light forgings. Larger pieces and heavier welds can be made at an ordinary forge. The sizes shown are best to practice on before undertaking larger work.

HEAVY FORGINGS

Any weld or forging that is too heavy to be man handled is classed as heavy forging, and the mechanical appliances used to handle them would require more extended explanation than we have room for. Putting pieces that weigh over 100 pounds together by welding, or forging pieces that weigh over 200 pounds each, is heavy forging.

ELECTRIC WELDING

A method of welding has been invented by Elihu Thompson, which appears to be capable of being employed with a variety of metals on a very extensive scale. In this, which is known as electric welding, a current of electricity heats the abutting ends of the two objects which are to be welded. These are pressed together by mechanical force so arranged with reference to the electric current that there is a great and rapid accumulation of heat at the joint, in consequence of the greater conductivity of the rest of the circuit. This method of welding in some cases, partakes of the nature of autogenous soldering, the pieces of metal being actually

fused while uniting. In other cases, as with iron, nickel, or platinum, the union may take place without fusion as in ordinary welding. In electric welding the pressure which forces the metallic surfaces together may, in the case of a plastic metal like iron, be either quiet or percussive in character. In autogenous soldering a more delicate and quiet pressure is generally preferred. In case of large articles hydraulic pressure can be used to force their surfaces into contact with each other.

Heating pieces with electric current at the junction to be welded is a good practice for many forms of welding in iron and steel, and makes the welding of other metals more simple. Bars butted together and clamped so that pressure between the abutting ends can be increased at will, become heated at the junction by electric current flowing through them until they are united by fusion or welded by sufficient pressure. As the electrical resistance is greatest at the junction, the metal welds without heating more than one diameter of the piece either way from the joint. And the practical uses to which the process can be put are many. Long seams of continuous welding in sheet steel or spot welding instead of riveting lap joints are easily accomplished by this process. It saves labor and time, besides being clean and accurate; and does not require the long training and experience necessary to learn how to make good welds at the forge.

THERMIT WELDING

Oxide of iron mixed with aluminum ignited in a crucible evolves heat twice the temperature of melted steel.

A definite quantity of iron heated in this way, and poured around the metal to be welded, heats the parts to be joined and unites with them into a homogeneous mass. Close fitting joints of broken pieces should be opened by drilling, and when a shoulder is to be formed around the joint, twice as much thermit as it takes to fill the space, and make the shoulder, should be provided in the crucible.

The chemical composition of thermit may be made to suit the kind of material that is to be welded. Thermit joints are by analysis and test for strength, the same as average steel castings. Large quantities of thermit heat so quickly as to be dangerous after being ignited in the crucible, steel

chips or punchings may be added to retard the evolution of heat.

Other metals than steel and iron may be welded with special thermits. But since its invention ten years ago, the process has been limited to the metals named.

HOT FLAME PROCESSES

Melt welds are made by heating with the flame of oil or gas. New welding machinery has been developed in the last fifteen years with which oxygen is forced into the flame so that intense heat is evolved and directed to the part to be welded.

Oxy hydrogen flame is twice as hot as melted steel, and quickly melts the material locally.

Oxy acetylene flame is 1000 degrees hotter and therefore more concentrated than oxy hydrogen; when the material to be welded melts in the flame the operator adds metal with a melt bar. High carbon steel, cast iron, copper and other metals can be united by these processes.

STRENGTH OF WELDS

A perfect welded joint is as strong as the metal of which it is made. Quite often it is refined and improved so that greater strength throughout that portion of a bar that has been lap welded is not unusual. But frequently patches of oxide or other impurities are left in the joint causing weakness that must be considered. Some handbooks for engineers advise them to subtract 30 per cent. for loss of strength due to welding, and if the material is to be used to its ultimate strength that figure is an average of the most tests the author has seen. But a safe rule is to use the elastic limit of annealed material as the ultimate strength of welded sections. Good welds always stand over 30 per cent. above the elastic limit of annealed stock before breaking, so this may be considered a safe load for welded joints.

COST OF WELDING

Without full information about the method of heating and handling welds, a correct statement of the cost can not be made. But we give here an estimate of the cost of labor and heat, for scarf and lap welding, one joint at a time, as has been illustrated.

½ cent for each 1/16″, including 1/2″ round stock.
1 cent for each 1/16″, including 5/8″ round stock.
1½ cents for each 1/16″, including 11/16″ round tsock.
2½ cents for each 1/16″, including 1″ round stock.
3½ cents for each 1/16″, for sizes over 1″ round stock.

Three-quarter inch diameters and over require two or more workmen, and the power and heat required increase approximately in geometric ratio, while the size is in arithmetical progression. Square bar welds are equivalent to rounds ⅛″ larger for each inch of the diameter. Flat bars are in proportion to squares. But the corners of rectangles are more liable to injury from excessive oxidation. This injury from too much air blast,in proportion to the fire, was explained in Chapter I.

EXCESSIVE OXIDATION VALUE

There is a value also to be gained from excessive oxidation, for with a blast of air at a pressure of two or three pounds per square inch, metal that is at the white welding heat may be kept in that condition where the blast strikes it while being forged into shape. If it is kept too long a time in this strong blast, the hot portion of the bar will be destroyed. It is rapidly burned unless it is worked upon quickly while exposed to this strong blast of air.

PART THREE

Part Three is on the treatment of steel, with instructions for making types of tools that are in common use

There are special things made, and many methods employed in certain shops that have no commercial value to us who may never use them, but we can read of them with interest. Even if we get no financial gain from the time spent in studying them, if they increase our stock of general information and knowledge of things pertaining to our work in life they are worth while.

The efficiency of a steel tool depends as much, or more, on the way it is treated by the toolsmith, as on the kind of steel furnished by the steel maker. We shall treat the subject almost entirely from the toolsmith's point of view. There are some things few toolsmiths ever think about. For instance, you have used files for many years, perhaps; some may think we had better files, or better steel, years ago than we have now. The file has been a standard test for hardness of other tools for more years than the writer has been on earth. Yet a little careful investigation of this common tool has resulted in great improvement as reported in 1907:

"A British machine was developed for mechanically testing files and autographically recording the result. The autographic record shows the cubic inches removed by a file from a standard test bar, the number of strokes taken, the period when the file cuts most effectively, and when it ceases to cut because of being worn out. The publication of comparative results obtained from tests made on files purchased in the open market created a sensation among file makers and file users. The difference between the best files and the poorest files was so great that a manufacturer clearly could not afford to use the poorest files, even if supplied free of cost. This result, of course, merely confirmed what every intelligent shop manager already knew, but the mechanical record of the actual difference in cubic inches removed and strokes made was a more definite proof.

"The valuable result of the file testing machine's work is the great improvement that has taken place since the file

maker was given the means of accurately testing his product. At the advent of the file testing machine, the best files were able to remove about 12½ cubic inches, and the best files were about twelve times as effective as the poorest. In 1907, two years after, the filemakers had so improved their product that the best file tested removed at the rate of eight cubic inches per 10,000 strokes, and 55 cubic inches of cast iron with one side of the file, or about four and two-fifths the total removed by both sides by the best files of two or three years ago.

"If it was possible to produce such a remarkable improvement in the hand file, simply because of the use of an adequate testing appliance, what might not be the result in other lines of manufacture, if rigid efficiency, so-called, is only comparative, and no one can say anything has reached ultimate efficiency. Now that attention has been called to that simple, yet perplexing tool, the file, it is entirely possible that its manufacture and action will not only be greatly improved, but changed. In fact, a radical change in file making has already been made."

Files are made of crucible tool steel, forged and hardened; they are a common standard testing piece for steel work done by toolsmiths, and this improvement in their quality will increase their reliability.

TEMPERATURES

The subject of steel treatment is not as well understood by artisans as it should be, but much progress has been made during the last decade. It is only in recent years that instruments for measuring high heats have been brought to such a degree of perfection as to make them of value to the experienced workman, and greater care and intelligence is needed to get more uniform results with the instruments than by the color of the heat radiated. In fact, one method should be used to check the other, as will be seen by a comparison of the following parallel tables copied from the same journal less than ten years ago, but published two years apart, as the temperatures corresponding to the colors commonly used to express different heats:

COLOR NAMES

TABLE 1.

FOR HIGH TEMPERATURES.

Dull red	1022° F.
Full cherry	1292° F.
Light red	1562° F.
Full yellow	1742° F.
Light yellow	1922° F.
Very light yellow	2012° F.
White	2102° F.

COLOR NAMES

TABLE 2.

FOR HIGH TEMPERATURES.

Dark blood red, black red	990° F.
Dark red, blood red, low red	1050° F.
Dark cherry red	1175° F.
Medium cherry red	1250° F.
Cherry, full red	1375° F.
Bright cherry red scaling heat	1550° F.
Salmon, free scaling heat	1650° F.
Light salmon	1725° F.
Yellow	1825° F.
Light yellow	1975° F.
White	2200° F.

"Different observers have quite a different eye for color, which leads to quite a different range of temperature covering the same color. Further, the quality of intensity of light in which color heats are observed influences in a great degree the determination of temperatures by the eye."

The difficulties in the way are again referred to in the Government reports of J. W. Reilly, Major Ordnance Dept., U. S. A., Watertown Arsenal, who says in the "Report of Tests of Iron and Steel," 1892, Vol. 29:

"It is intended to extend the observations to a general investigation of the subject of tempering steel, operating with steels covering a wide range of chemical composition. Much obscurity at present surrounds this subject, and it is not generally understood what treatment is necessary to produce maximum results as regards strength, or how the physical properties may be controlled by varying the tempering methods."

CHAPTER VIII

FORGING STEEL AND TOOL SMITHING

Forging carbon tool steel has a different effect upon the metal than similar operations on wrought iron or machinery steel because the crucible tool steel has that energetic element carbon in it, so combined with the iron and of such quantity that the structure and properties may be completely changed by the treatment. When one knows what physical changes of the properties to expect from different methods of treatment, learning how to forge it becomes a simple problem to one who knows how to heat and hammer into shape wrought iron, or the soft steels now so commonly used in place of iron.

THE HEATING FIRE

Crucible tool steel should be more carefully heated than the other materials of which forgings are made, and the intensely hot and rapid fires of gas or oil, so well adapted to heating the metals forged by others, should not be used by the toolsmith. His fire should be made of clean, soft coal, well charred or coked in sufficient quantity to cover the pieces as they are heating, and if there is a suspicion of sulphur in the fire it should be cleaned out, because red hot iron will absorb sulphur, and it is one of the worst enemies to steel. As iron absorbs sulphur, and we are not so particular about the injury to it, a heavy bar kept red hot in a fire for five or ten minutes may be used to take up the sulphur before heating the steel.

PROPER HEATS

Get the steel hot enough; don't be afraid. Toolsmiths have heard too often that time-worn advice, "Don't overheat the steel." Get it as hot as it will stand without injury and pound it hard; it will stand a yellow heat — work it fast, with rapid, hard blows until it is reduced to as near the size and shape you want it as can be done at one heat, and if cracks or flaws can not be seen, the high heat did not hurt it.

Now, if the piece has been made nearly the right size by this working, don't get it so hot next time, but finish off the corners, edges, flat surfaces, and do the bending or straightening at only fair red heats.

When a piece of crucible steel is to be reduced in size, say one-half, by hammering, it should be heated more than red hot. If it is not more than 120 points carbon, it will stand a bright yellow heat without injury, and if it is hammered promptly and thoroughly, the same amount on both sides until it is a dull red, it will be as tough and strong as it can be made without the special treatment of tempering.

If it is not well hammered while cooling from that high temperature it will be brash and weak, coarse-grained, poor looking stuff in a fracture; the hammering hard enough to affect the piece clear through its diameter with blows as rapid as they ought to be, prevents the growth of large crystals, which make the coarse grain, and if the hammering does not cease instantly at the dull red heat, just before the dark blue spots appear, the grains will be broken apart inside under the skin. That scaly, packed hammered surface may look smooth and perfect, but the steel is ruined inside, and can never be of much service as a tool.

There is greater danger in working the steel too cold than too hot, for if it is overheated and instantly struck a good forging blow it will be so cracked, checked, or bursted, that any careful man will know better than to try to use it for a tool, while if it is not hot enough when it is worked, the flaws are inside and may not be discovered even when the tool fails too quickly in service.

CUTTING AND HAMMERING STEEL

The percussive force of hammer blows is better for steel than pressing or rolling. Crucible cast steel that is intended for cutting tools is reduced from ingot size, which may be ten inches or more in diameter, by successively heating and hammering until it becomes the size and shape required, then it is nicked and broken into lengths convenient for handling as commercial bars of flat, octagon or round; the rounds of tool steel are not finished in a swage or die, as iron or soft steel would be, but like the other shapes are finished on a plane anvil with a smooth faced hammer.

Carefully observe tool steel bars and the inequalities usual to hammered work with its sharp corners and edges unlike drawn or rolled steel can be easily distinguished. So the bit or point of cutting tools should be hammered as nearly perfect as possible in size and shape to make the best tools.

CUTTING COLD STEEL

When a bar of tool steel has been nicked with a cold chisel, file, or grinder, it can be broken by striking it a sharp blow with a sledge, and this is the usual way of getting pieces the right length for tools. But it is wasteful of material, though saving of time, for it would take a deal of good time for a workman to heat and cut the lengths off with a hot chisel, and it is cheaper to waste the stock than to spend the extra time, as the portion of the steel that is shattered by the cold breaking does not extend far into the bar, and the quickest and best way of finishing tools is by cutting off the ragged edges before or after the heavy forging is done.

FORGING MACHINE TOOLS

Fig. 1 shows how to hold and hammer stock for a cold

Fig. 1.

chisel; a round nose lathe tool is held and hammered in the same manner until it is the right width and thickness.

Fig. 2 shows the usual way of cutting a round nose lathe tool to shape after it has been hammered; it should be cut on line at the proper angle across the end to give the clearance necessary.

Fig. 2.

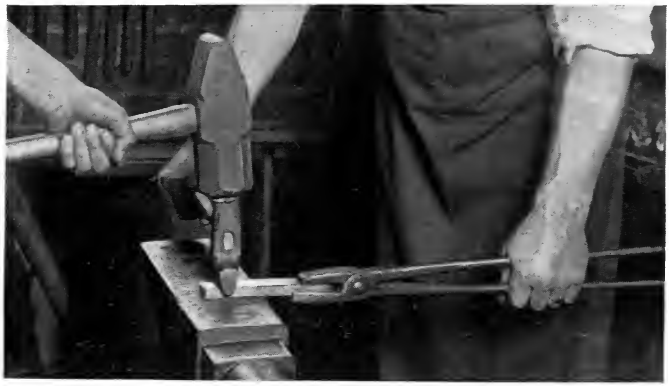


Fig. 3.

Fig. 4.

A series of eight illustrations showing the manner in which to handle a common type of machine tool that must be made at the forge, is shown here. When the steel is at a good forging heat, a fuller mark of the proper depth to leave thickness of stock right for the bit of the tool, is made as shown in

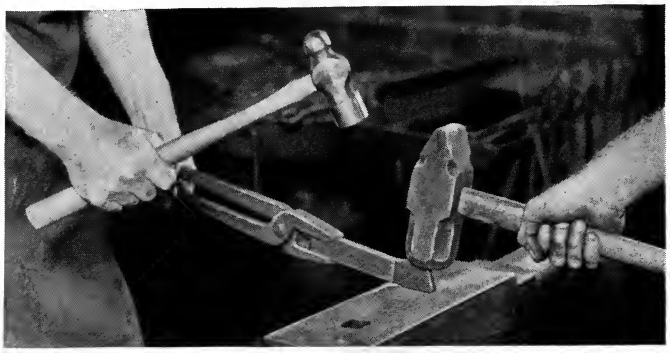


Fig. 5.

Fig. 3. It is then turned to the position shown in Fig. 4, and a few blows struck with the hammer and sledge; then it must be turned edge up and hammered lightly, see Fig. 5. Back and forth to these positions, the piece should be turned while it is being hammered to the length and thickness required.

Finishing the edges and flat sides of the bit may be done more quickly with a set hammer or flatter; both flat sides should be turned up to get the effect of hammer blows during the final smoothing of the surfaces, and the top or

Fig. 6.

cutting edge should be turned up and given the final hammering to pack the grain and smooth its surface so that little grinding is required to bring it to a keen edge. Now the tool should be cut with a hot chisel, as shown in Figs. 6 and 7, to get rid of the surplus width on a thin tool that can not well be hammered as narrow as it ought to be without breaking the grains apart as previously described, and for the end clearance necessary to the purpose for which it is to be used.

Fig. 7.

CLEARANCE ANGLE

The end clearance is usually close to 15°. In Fig. 8 a cone set up on a face plate is serving as a test for this angle, and also as a measure for the slope in the forged bit. As the

Fig. 8.

line around the cone is ⅛″ higher than the top edge of the stock of the tool where the hammer rests on it, and the end of the bit rises to the line, the slope of the tool is forged ⅛″. It is customary to cut more clearance on the end of forged

tools than will be made by the grinder, therefore the tool in Fig. 8 tests right for slope and end clearance, and can be seen to have a bearing the full length of the stock on the level face plate, as all tools of this kind should have.

The bit of a cutting off, or parting tool, must be thinner on the bottom than on the top edge; this is for side clearance, and can be tested by the vertical post set up on the face plate. When the corners of the top edge of the bit touch the post and the lower corners do not, while the tool is level on the plate as shown in Fig. 9, there is enough side clearance for such tools.

Fig. 9.

BENT TOOLS

A lathe tool of this kind is sometimes bent at the shoulder left by the fuller mark. This makes it more convenient to use as an outside threading tool. A 30° angle is usually correct and is being tested to that degree in the illustration,

Fig. 10.

OFFSET EDGES

Another form of machine tool is made with an edge along one side of the bit which may be used for cutting with its full length, instead of with the end only, as those already shown are made to do. These are called side cutting or facing tools, and as they are to have clearance on one side only, the fuller mark should not be made clear across the flat side of the stock, but should be made, as shown in Fig. 11, deep enough on one edge only, to leave half of the stock, which is a common thickness of edge for the bits. The piece is then held and hammered in the positions shown in Figs. 4 and 5, and the surplus material cut from the bit as in Figs. 6 and 7. Then the top fuller is used again as shown in Fig. 12 to offset the edge from the body of the stock twisting the bit for side clearance of 15° as shown on the testing plate in Fig. 13.

Fig. 11.

Fig. 12.

The cutting edges of these tools are usually on the left hand side as shown in the illustrations. Bits forged on the right hand side, make *left handed tools,* which are sometimes called for, but are not so commonly used in machine shops.

Fig. 13.

Fig. 14.

SHANK TOOLS

The diamond point tool is forged as it is held in the positions shown in the four illustrations. Fig. 14 shows

Fig. 15.

how the fuller is used to make the throat or shank of proper depth and length. Similar tools may be forged without this fullering for a throat by bending the full sized stock down and then holding as shown in Figs. 15 and 16 to hammer the shape required. The slope of this tool is cut with the hot chisel as shown in Fig. 17; that side of the bit on which the cutting edge is to be, is resting on the anvil, and the hot chisel should be made to go through the piece so the cut will be finished on the side intended for the edge of the tool

Fig. 16.

that is being made; this is important with all hot cutting to make machine tools.

Fig. 17.

Boring, and inside threading tools are fuller marked on one edge of the stock, the same as in Fig. 14, far enough from the end to allow stock that can be drawn to the diameter

Fig. 18.

and length desired. This work is done with the hammer and sledge as shown in Figs. 18 and 19. The shape of steel pieces is finished on the flat face of the anvil; rounds of tool steel should not be swaged, but the flatter may be used if desired to smooth and straighten the forging more quickly and per-

Fig. 19.

fectly than it can be done with the hammers. Bits are bent over on the ends of these forged shanks, hammered and cut to the shape and length desired; rake, slope and clearance must be provided, and may be tested as on other tools.

Forging such machine tools as are shown in Figs. 20, 21 and 22, is done by the right combination of the operations that have been described and illustrated.

HIGH SPEED TOOLS

Some self hardening steels must be forged at lower heats than carbon tool steel will stand. High speed tools are made of steels alloyed with other metals, and must be kept at a high heat when forging, as is more fully explained in Chapter 9.

THE TIME REQUIRED

A good toolsmith and helper can make and finish ready for grinding from eight to sixteen tools per hour. If he makes sixteen tools of a kind similar to those shown in the preceding Figs. in one hour, he will have to work fast and leave them so rough that it will take the machinist who grinds them about two hours to get them ready for work. On the other hand, if the toolsmith and helper spend an hour making eight well finished tools, the machinist can grind them ready for work in about thirty minutes; otherwise there is no difference in the tools, one lot can be made to do as much work as the other, for in either case the toolsmith that knows how to treat the steel will fix the physical structure and the properties of the metal in the best condition for the purpose for which it is to be used.

THE FORGING TOOLS USED

For steel of the dimensions shown ($1\frac{1}{8}'' \times \frac{1}{2}''$) the smith's hammer should weigh not less than $1\frac{1}{2}$ lbs.; $1\frac{3}{4}$ or 2 lbs. would be a better weight, and will do on heavier stock as well.

The helper should have at least an eight-pound sledge, but a 12-pound sledge is necessary on heavier stock; $1\frac{1}{2} \times \frac{3}{4}$ inch tool steel cannot be properly forged with less than a twelve-pound sledge, and if the steel is much thicker than that a still heavier hammer will be required.

A top fuller, a set hammer, a flatter and a hot chisel are the other tools used in addition to the anvil and fire. With these a toolsmith can make all ordinary cutting, punching, and battering tools of carbon steels, such as are shown in Figs. 20, 21 and 22.

When the learner can use these tools as they ought to be used on crucible steel, and follows the advice given here, he will have the forging in good physical condition, and it may be laid by to cool off, and to season for a time before receiving further treatment.

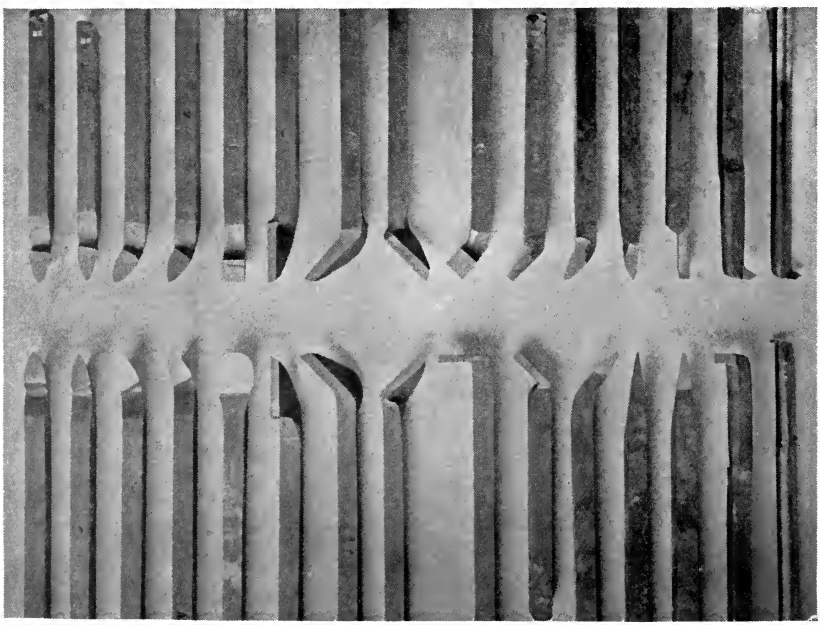


Fig. 20.

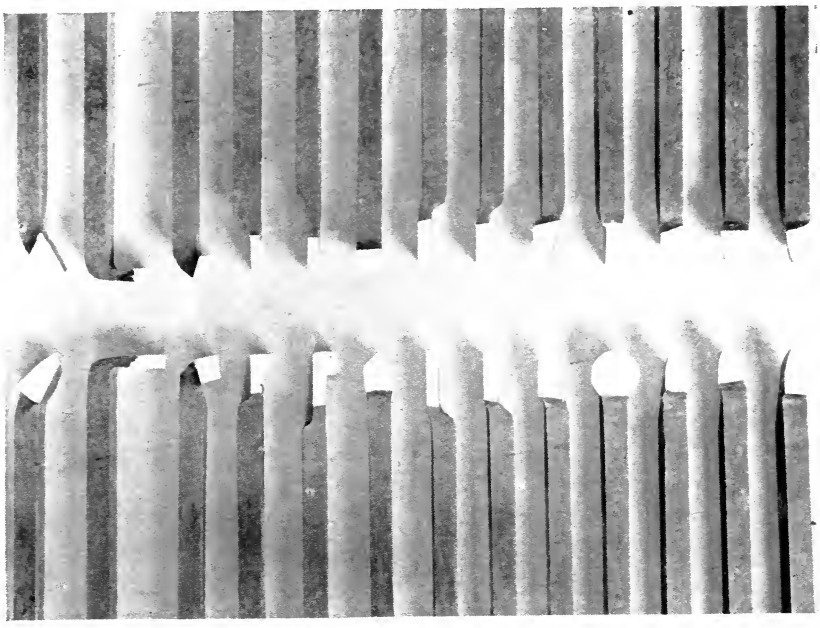


Fig. 21.

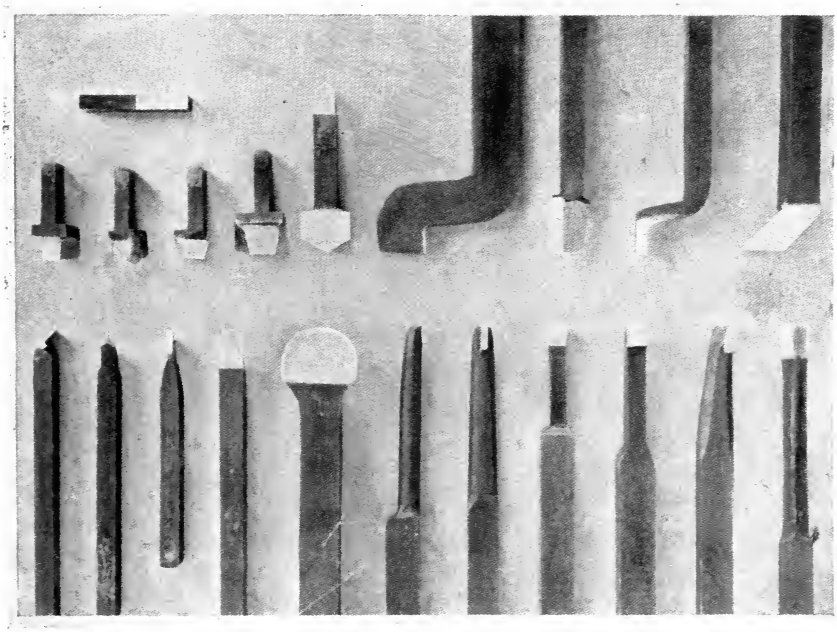


Fig. 22.

CHAPTER IX

HARDENING AND CARBONIZING

After steel is forged and has been allowed to season it is ready for further treatment. By seasoning it may be understood that it is properly annealed, or returned to its normal condition, at least, if it is left in a dry place to cool down from a red heat to the temperature of the atmosphere, it will be in its natural condition, and less liable to crack or burst when hardened, as tools so often do when the strain of sudden cooling is added to the forging strains. Besides this, there is sometimes much internal heat left in a piece that has just been hammered, and, if it is immediately returned to the fire, the steel may accidently get too hot for proper hardening before the operator is aware of it.

High carbon steel that has been machined or ground before hardening should be carefully annealed before the hardening is attempted, as such pieces are much more easily affected by heating and sudden cooling, for they have not the strong, tough hammered skin which protects the forged pieces to such an extent that with ordinary tools, such as cold chisels and lathe tools, it is not an uncommon practice to proceed at once with the hardening and tempering. It can generally be done by a careful workman before the forging heat is all lost, but it is not the best practice.

The processes and effect of annealing and tempering will be discussed farther on. Here we must consider hardening only, and the importance of having steel in the right condition, for the process must not be neglected, or many water cracks, flaws, and broken pieces will be the result. Failure to get the steel at rest before it is subjected to the violent shock of transformation from the soft and pliable state to one that is hard and brittle, causes many of the so-called mysterious breaks known to steel users.

WHY DOES STEEL HARDEN?

The reason why steel hardens can not be stated in terms that satisfy all investigators alike. It is a phenomenon

that has never been explained fully and probably never will be. Much has been said and written about it that is true, and the microscope has shown to metallographists many facts about the changes that occur in the manner of the arrangements of the grains during hardening. The different color of these grains indicates that a new substance has formed, which we call "hardenite." A peculiar feature of the subject is that only one grade of carbon steel can be changed entirely into hardenite. That is, 80 point carbon steel when hardened appears when polished and etched for examination under a microscope to be a solid mass of the substance so named, see Fig. 1. While if the percentage of carbon in the hardened steel is less than .8%, patches of another substance known as "ferrite" may be seen, as in Fig. 2, and high carbon (over .8%) shows a different kind known as austinite, like Fig. 3. Ferrite will not harden, cementite and pearlite will, and one or the other of them is always found in the steel that is not hardened. Low carbon unhardened steel shows a structure of pearlite and ferrite; in medium carbon unhardened steel all pearlite; in high carbon unhardened steel pearlite and cementite.

Fig. 1.

Fig. 2.

Fig. 3.

The portion that was pearlite is changed to hardenite if a piece of steel is cooled quickly from a high temperature, and in very high carbon steels so hardened, still other substances known as "austinite" and "martensite" may be seen. These grains are a new development of hardenite and differ but little from it in appearance, but it is sufficient to show that steel higher than .8% carbon is transformed by the growth of new granules within it which make it preferable to the medium steel for some kinds of tools that have hard, heavy cutting to do.

The fact is well known that 99.2% iron combined with .8% carbon makes a perfect compound, an alloy that is uniform throughout, and this saturation of iron with carbon may be called the only pure steel, and is explained more fully in Chapter XI. However, steel tool users find that when carbon is higher, keen edges will last longer, and with less carbon in the iron, tougher battering tools that are strong and hard enough may be made.

From time immemorial, toolsmiths have said, "cool the steel quickly when you have it right." The heated condition is fixed by sudden cooling. By quenching we cause the steel to show itself as it was when hot. A rapid cooling gives the status quo, the state into which the steel was brought by heating; sudden quenching fixes the hot condition, making the metal in a cold state show itself as it was when hot. Steel workers have handed down this idea from generation to generation, and until scientific investigation has agreed upon a better and clearer answer to the question, the writer has concluded to accept the traditions of men who make and treat the metal for the many uses to which it is applied.

HARDENING CRUCIBLE STEEL

This is done by cooling it suddenly from a high temperature. The manner of heating and cooling has nothing to do with the hardness, but much to do with the other conditions of the tools. Warping, bending, and checking the piece, usually result from careless work. Generally speaking, the hotter the steel is made and the more quickly it is quenched, the harder it will be, but as too high a heat will make it coarse grained, and very sudden quenching will often crack a piece, both of these things must be carefully studied.

Degrees of hardness are not easily defined and not understood alike by all. Steel that has been too hot when quenched will be more brittle and seem more hard by some tests than steel that is heated to the proper temperature and cooled at the best rate for that quality of steel, but it is weak in structure and useless for cutting tools. It will scratch glass, but it is liable to crumble, so it is best to concede that steel which is refined and made strong in structure by the hardening process is at the maximum hardness for that steel, because it is hardened to make the tool endure battering, pushing or sliding on, or into other material. Therefore, the mere fact that a diamond will scratch less deeply into coarse grained or improperly hardened steel, than into that which is properly treated, has little value to us in our present limited knowledge of the mysterious phenomenon "hardening," which changes structure and condition without altering the composition. We will show now how steel should be treated for proper hardening to what should be called its maximum hardness.

HOW TO HEAT STEEL FOR HARDENING

Small tools that have been hammered may be heated in the forge fire. There is no better fuel than good smithing coal for such work. The fire should not be excessively hot, and the fuel should be well charred or coked, with plenty of it to cover the piece. It should be glowing red, so that the steel may lie on a bed of coals at least five inches above the tuyere, and have a bank of red coals on each side of it, with several inches of fire over it, so the heating will be uniform, gradual, not too fast, and with as little oxidation as possible.

OXIDATION

Pieces that have been machined or ground before hardening are more liable to injury by oxidation than those protected with the skin made by hammering. A skin of oxide is formed on every piece that is heated to 400° F., at this temperature and up to about 1000° F., which is a low red, it is only a color that injures the material in no way except as a stain, but at a higher temperature a thick scale is formed, and the surface of a piece is left scarred and rough where the scale peels off. A well kept forge fire of good coal is not as bad for oxidation as gas or oil fires where the pieces are heated in the product of combustion. Even if the steel is heated

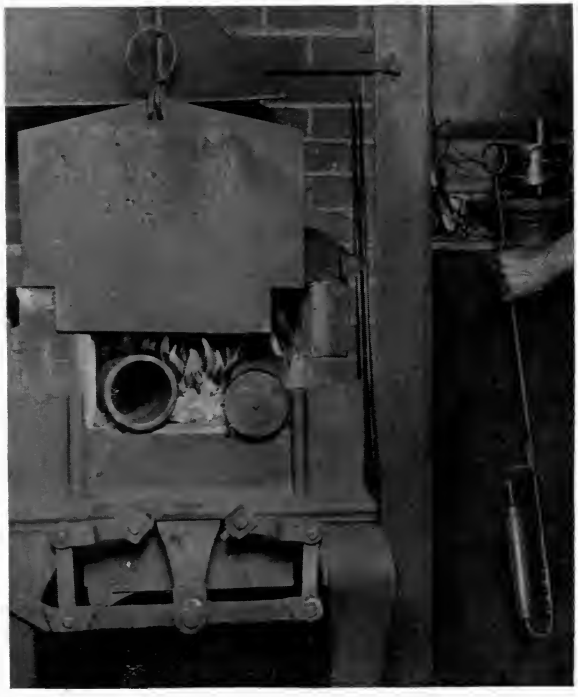


Fig. 4.

in a muffle, hollow tile, or pipe, as shown in Fig. 4, that can be closed at both ends, enough oxidation will take place to stain or color the pieces. Besides, there may be injurious chemical action from the gases, and red hot steel absorbs impurities very readily and is poisoned by some of them. Take the best available method of heating and get the steel just hot enough and plunge it immediately into the cooling bath. That is, do not let a piece get a little too hot and allow it to cool down in the fire or in the air before quenching. That would be quenching it at a falling temperature and retaining the condition it was in then, which is not the same as the transformation which takes place in steel when it is heated up to the right temperature, and the excess of oxidation at heats higher than necessary, is therefore, only part of the probable injury.

Scaling causes some reduction in the size of a piece and makes the refinishing after hardening a more expensive process. This can be lessened by heating in a bath. Alloys can be prepared which melt at known temperatures. (See tables in Chapter IV, page 64) and the heat of the steel placed in them may be regulated with a great degree of accuracy.

LIQUID BATHS FOR HEATING STEEL

The most common use has been made of melted lead. Very accurate results can be obtained, particularly if a pyrometer is used to test the heat of the bath. In Fig. 4 the tempreature of the furnace is shown by the instruments to which the wires are attached. The same effect can be produced as often as desired with this apparatus, for the slight changes in air pressure in the fire and the condition of fuel that might contribute something to steel that was amongst the coals would not affect a piece that was inside the closed pipe or a pot of melted lead, whose temperature would remain fairly constant throughout the usual variations of a fire or the atmosphere. But the oxidation which colors polished steel would occur to some extent while the piece was being passed from the pipe or hot lead bath to the cold water bath, and some lead is apt to stick to it which hinders cooling. Besides this, the impurities of commercial lead at high heat may alter the chemical composition of some steels, and for very high temperatures, such as are required for some of the alloy high speed steels, the pipe would melt, and lead can not be

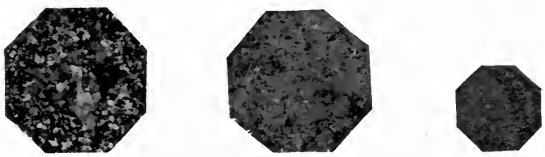
used. Mercury, chloride of barium, metallic salts, and common salt are sometimes used as heating baths, and do not give off the poisonous vapors that arise from lead at high temperatures. Cyanide of potassium, which is used chiefly for the chemical effect it has on red hot iron, is poisonous to human life and gives off fumes at all temperatures that are injurious. Its use will be more fully described under the head of case hardening.

Pure lead melts at 617° F. and can be heated to double that temperature without difficulty, but it gives considerable trouble at high temperatures on account of oxidation.

Barium chloride melts at a little below 2000° F. and can be heated several hundred degrees above that point in a crucible of clay or graphite. A spoonful of soda ash will prevent its fuming, and as a film of barium chloride will stick to a piece until it is quenched, no oxidation can take place on tools heated in this bath. However, the high melting point precludes its use for ordinary carbon tool steels, as they must not be above the point of transformation of the grain, which occurs below 1600° F., when they are dipped in the cooling bath.

THE EFFECT OF HEAT ON STEEL

If crucible steel has been too hot when it was quenched, or when the last forging was done, or when laid by to cool, the structure will be coarse grained, like the first piece in Fig 5. The crystals will be large, and as the connecting places between large crystals are great, and it is a separation of crystals that causes steel to break easily, coarse grained steel is weak in structure whether it is hard or soft. Therefore a fine grained piece, like the last in Fig. 5, that is composed of the right elements is in the best condition for cutting tools. This illustration is a photograph of fractures through ¾" octagon tool steel of .8% carbon. After it was overheated and kept at a high yellow heat for five hours and annealed, the grain size of one portion was refined by proper harden-



Coarse grain Overheated and annealed. | Refined by hardening after overheating. | Refined by hammering after overheating.

Fig. 5.

ing. Another piece was refined by forging to half size before hardening. A cutting test was made and the small piece was found to be not greatly inferior to steel that had not been overheated. The piece in the middle of the illustration was not as good as the one on the right, but better than the left hand piece.

EXAMINATION OF FRACTURE

If the composition is iron and carbon only, (which forms the only true steel when properly combined) the proper hardening heat can be quickly determined by the following experiments: Break a piece from the forged bar of carbon steel, and the grain will be bright and even with a light grayish color, and not very fine or small except perhaps around the edges where it has been packed by hammering. Now heat a piece of the same kind of steel to a low red and plunge it into water, keeping it under and moving it about to break up the film of steam that would surround it and prevent rapid cooling, and when it is cold and dry, break off another section. This fracture will appear more dense, a darker gray in color, with signs of tearing or a striated fracture, showing even, close, fine grains or crystals very small. The steel has been refined by hardening, because the heat was right for that kind of steel, and it is a fine strong silky fracture as it ought to be.

If another trial is made at a high heat, the quenched piece will show a fracture that is coarser grained, and by holding it at the high heat for some time, the crystals will grow very large. These crystals are fixed by sudden cooling and are made very bright and sparkling. Any sparkling lustre in the fracture of a hardened piece indicates that it was too hot when quenched; so it is by the lustre, as well as by the size of the grain, that a fracture tells the story of heat treatment. If the piece was not hot enough for perfect hardening, or the heating was done quickly, it will not be thoroughly refined. See Fig. 6. Though it may be partly hardened, it is not in good condition of structure for a cutting tool.

Fig. 6.

THE RIGHT HARDENING HEAT

The heat that refines any steel is the only proper hardening heat for that steel, and this heat varies with the carbon content. For 120 point carbon steel it is

below 1150° F., or a low red heat. If the carbon is high, the heat should be low and vice versa.

Therefore, the following rule applies to all crucible steel: For high carbon (1.50% or more) a dark red heat, 1050 degrees Fahrenheit or less. For medium carbon (1.00% or less) a medium heat, low red about 1150° F. For low carbon (.50% and upward) heat to a full bright red, not over 1500° F.

The exact temperature for any steel can only be determined by experiments such as have been outlined above, and the rule given is intended only as a starting point from which to begin the experiments, as there are always present in steel some other elements besides iron and carbon, which have some effect on the results. These experiments must be made frequently by the toolsmith and his method varied accordingly.

CRITICAL TEMPERATURES

Tool steel that is being heated may be seen to glow suddenly, from a dull red to a clearer color, without any increase in the temperature of the fire where the coals are glowing red. The metal at a certain point increases its own heat. This is when the change in crystal size begins. It is the point of transformation, and the heightened color is caused by the action of the grains upon each other or amongst themselves. It is well called the critical point, for if now the fire is too hot this excess of heat being contributed to the steel while it is so agitated as to be raising its own temperature, will quickly overheat the piece to a degree that will create large crystals and a weak physical condition which is preserved by sudden cooling. The critical stage is at about 1100° F. in ordinary carbon steels, and as it is the point where crystals or grains that were large, irregular in size, or distorted in shape by previous treatment, such as bending, twisting, or pounding, begin returning to their natural size and shape; it is near the temperature at which the piece should be quenched to make it hard and to keep it fine grained and strong. The hardenite is forming at the critical temperature, and it is complete within a range of not more than 10 degrees above it, so any piece that is heated more than that will not be as fine grained as it ought to be when hardened, and if it was dipped when not so hot, only partial hardening, or imperfect structure of the steel would be the result. A curve showing critical and recalescence stages is given in Chapter XI.

RECALESCENCE

Steel that has been heated to a full red heat may be allowed to cool in air, and if held in a dark place, when the color of the steel has turned to a dark red, a sudden glow of brighter color may be observed which indicates an increase in temperature. This is the point of recalescence. The steel reheats itself for an instant by the transformation of its granules from one size and kind to another, and then the gradual and regular rate of cooling is resumed. Some steels have two or three such points, and they correspond quite closely to the points of transformation when the piece is being heated. The temperature of recalescence as well as the critical heat or transformation point varies with the carbon content of the steel. As it is the only perfect hardening point for any steel, the heat at which it is made maximum hard by proper quenching, those heats should be studied in every possible way. High carbon steel is transformed at a heat very much less than that required for medium or low carbon steels.

Hardened steel lacks magnetic permeability, but has magnetic retentivity. Unhardened steel lacks magnetic retentivity but has magnetic permeability until it is heated up to the critical temperature. Here its magnetic properties are suddenly lost. This fact is used in the laboratory for finding perfect hardening heats without depending on the eye for color, or the pyrometer for measuring temperatures, and it may be put to common use by toolsmiths.

COOLING BATHS

The most common medium is water for cooling steel to harden. This does not reduce the heat of a piece plunged into it as fast as mercury would at first, since mercury is a better conductor of heat, but water will take up more heat than mercury, and will cool the piece down to the temperature at which hardening is complete, or below the boiling point of water as quickly as it usually needs to be done. Mercury takes up heat rapidly; it gets hot quickly and soon is raised to a temperature of 648° F., where it boils, and steel is not completely hardened at that temperature. Hardening is finished at the boiling point of water, 212° F. Therefore, it makes very little difference how hot the water is, because the rate of cooling a piece through 1000 degrees by means of ice

water is but little faster than with hot water, and it is the cooling *rate* that fixes the fine grains and hardenite of the steel. These are permanently fixed in the steel as soon as the temperature of 212° F. is reached, and will remain in that condition as long as the piece is kept below 212° F.; at this point softening begins in hardened steel. That subject will be dealt with under the head of tempering.

The water for hardening should be clean, and for perfect results must be pure. The impurities in hard water are likely to affect the results, but, as has been said about the heat of the water, there is no practical appreciable difference, unless water is so foul as to retard the cooling rate. Good, clean water is what is meant, and its effect is better if some salt is added. Alum, soda ash, sal ammoniac, and other ingredients are sometimes put in the water used for hardening, but are of no particular value except to preserve the bath and cause the surface of the steel to have a different appearance. Salt makes the chilling effect more constant and regular, as well as more rapid, while soda ash or alum makes the scale come off more freely and brightens the piece. Some of the stuff put into the water by experimenters may have a chemical action on the steel, which is more likely to be injurious than otherwise. So clean water is recommended for all ordinary tool work, and salt may be added in any quantity that pleases the hardener without fear of changing the results very markedly.

HARDENING IN OIL

Fats, tallow, grease, and oils are used for cooling some kinds of tools made of high carbon steel. When the piece to be hardened is of such shape that it is liable to crack in water, it can be dipped with more safety in grease or oil. Tools that are made with thin parts joined to thick parts, with sharp corners and angles, are very liable to break when hardened. The cooling rate in oil is slower than water, but sufficiently rapid to fix the hardenite in high carbon steels, if the section is not too large. Fish oil, linseed oil, and lard oil are chiefly used and recommended in the order named. Mineral oils are not dependable and give off foul odors that would make them objectionable, even if the results obtained by their use were found to be good. Fish oil is used especially for spring steel.

Car springs, carriage springs, and the like are usually hardened in it. The material of which springs are made is peculiarly liable to crack if hardened in clear water. It can, however, be done successfully in distilled water having enough

Fig. 7.

soap in it to make its chilling effects the same as oil. A blast of air is often used and cools some steel rapidly enough to make it very hard, but such steel usually contains as hardeners other elements than carbon, and is not in a true sense steel, but an alloy of steel, requiring special heat treatment that is mentioned in another paragraph of this chapter.

AVOID WARPING AND CRACKING

Chilling one side of a red hot piece before the other is chilled will cause it to warp or bend. Tools strained in this manner are liable to have cracks or flaws occur in them during the quenching. These defects are called water cracks. They show like hair lines on a smooth surface, and usually the steel can be broken easily at a water crack. Sometimes they are not deep enough to spoil the tool, but are an injury to be avoided. When water cracks are broken open, the fracture may be seen *colored with some stain of oxidation.* If the fracture is not some shade of the oxidation colors — yellow, red, and blue — it indicates that the flaw was caused by some error

Fig. 8.

in forging or other treatment. An unequal heat on opposite sides of a piece, or plunging sidewise into the quenching bath may cause the hardening cracks or water cracks so often made by careless workmen. Properly heated steel held vertically over the cooling fluid and plunged straight to the proper depth, as shown in Fig. 7, will not warp or crack.

Tools that are to be hardened on one end only should have that portion properly heated and held in the water until it is cooled below the boiling point of water. When the cutting edge is of some length along one side of the tool, that edge should be kept under water until cold, while some heat may be left in the opposite edge. Fig. 8 shows how a side cutting tool should be turned edge down in the water.

Fig. 9.

MUFFLE FURNACE

To protect from injury in the fire, a muffle of fire brick may be used. In Fig. 9 some pieces of charcoal have been placed in the muffle to use the oxygen and keep it from injuring the steel by absorbing the carbon from the surface, so that a soft skin outside of the hardened steel might result.

PACK HARDENING

On the hearth in front of the muffle furnace, in Fig. 9, is a short hollow shaft with two pinions projecting from opposite sides of a collar at the middle of the shaft. The collar and pinions only are to be hardened. Therefore the hollow shaft is filled with fire clay kept in place by a cap of tin-plate; the rest of the shaft is protected with tin-plate or sheet-steel wrappings kept in place with binding wire. When heated and quenched, only the uncovered parts of the piece will be hardened. Asbestos wrappings can be used to protect parts from the quenching bath as effectively, for properly covered parts protected from the cooling bath are not chilled rapidly enough to be hardened.

HIGH SPEED TOOLS

High speed tools were brought successfully into use in 1900. Previous to that time, Mushet steel was the only metal known that was superior for some cutting tools to carbon steel.

Mushet steel contains carbon, tungsten, and manganese, and will harden in air, hence it is known as self, or air hardening. As it hardens itself by getting cold, perhaps it would harden in a vacuum? The common practice with it is to lay the tool, after it is forged, before a nozzle through which air is taken from the blast which blows the forge fire. Here this kind of steel becomes as hard as it can be made, and is ready for use without tempering. If the heat generated by the work is sufficient to make the tool red hot, its edge will fail as ordinary carbon steel would; but unlike the carbon steel, the self-hardening steel does not have to be reheated and tempered again before it is fit for use, for while the carbon steel loses all its fixed hardness at 800° F., Mushet steel does not, though its edges will fail to cut at that temperature.

The elements tungsten, molybdenum, chromium, vanadium, or titanium may make up twenty-five per cent. of a

metal now used for hard and fast cutting tools. There are other alloying elements used, but at the present time two or more of the metals named are added to steel of about one per cent. carbon to make a metal that is known as high speed steel.

The newer alloy high speed steels have the advantage of red hardness, and can not be forged, bent, or battered greatly at a full red heat. In fact, the forging must be done at a bright yellow heat, and the proper hardening heat for them is still higher. They should never be dipped in water for hardening, but in oil, or left in the atmosphere or air blast until cold. These alloy tools have greatly increased the speed at which work can be done in the machine shops, and have simplified the work of the toolsmith in the matter of hardening, while no tempering is necessary for them. The forging is more difficult, but after learning to work carbon steels, high speed steel can be successfully treated by following the instructions given by the steel makers. These instructions may differ in details, but the simplest way will give good results with any of the alloys in common use.

Prior to the introduction of these new tools, forgings could be made faster than they could be rough turned and machined, without much fitting or finishing. The new thing is a process of treatment for alloys of steel, rather than a new steel. And its development is chiefly due to the successful experiments of Messrs. Taylor and White, with the Bethlehem Steel Company's products.

TREATMENT OF HIGH SPEED TOOLS

The so-called high speed steels are easier to forge than the older self hardening products. Toolsmiths were warned not to get Mushet or Jessop air hardening steel to more than a red heat. It could be treated at 1500° F., but 1600° F. was the limit, called the breaking down point. Above that temperature the tool crumbled if touched, and was said to be burnt. The remarkable cutting that could sometimes be done with this burnt steel, doubtless led to the development of the high heat treatment for tools made of steel alloyed with some of the chromium group of metals. The amount of carbon in these tools has no influence over the treatment, which is the same though carbon content varies from 80 to 200 points. After the tools are forged to shape, they should be rough ground nearer to the size and angle than it can be well done at a forge.

TO HARDEN HIGH SPEED TOOLS

Heat to a dazzling white or like a welding heat for iron. When the tool is sweating, the edges almost melted, plunge it into oil and keep there until cold. No other treatment is needed. It is ready to grind for use. If some of the corners have dropped off under the influence of the excessive heat, the chief harm done is loss of the melted portion, for the structure will be fine and good in that which remains after grinding. However, by careful handling, it is not necessary to lose any of the metal. Some toolsmiths prefer taking the tool out of its oil bath as soon as the high heat is brought below redness on the portion forged for the bit. This latter practice will strengthen and toughen the bit by means of the internal heat remaining in the stock.

The exact temperature from which to harden some of the high speed tools is given as 2000°F. From this, cool them rapidly in liquid down to 1500° F., then slowly or naturally in air. After they are cold, reheat to 1200° F., keeping them at that temperature for ten minutes, then allow them to cool slowly and they are ready for use. High speed tools do not lose their fixed hardness at temperatures below 1100° F.; but in comparison with carbon steel tools or air hardened steels, that have been properly treated, they are not very hard. What hardness they have is retained at such a high temperature that cutting speed can be increased many times without damage to their cutting edges.

CASE HARDENING

Case hardening is converting the exterior of a piece of iron or soft steel into hardened steel, leaving the inside soft. It is best done by packing the piece in a box with carbonizing material and heating for a length of time sufficient to allow carbonization to the desired depth, then cooling the piece suddenly in water.

Cementation

Carbonizing is done in the same manner as making cement steel. In the cementation process of steel making, bars of wrought iron are packed in a furnace with alternate layers of charcoal. The furnace is sealed to prevent escape of gases and the passage of air currents. Then the inside is kept red

hot for a time sufficient for the carbon of the charcoal to penetrate the iron to its center. This may take days or weeks, according to the thickness of the bars.

If only a thin skin of carbonized iron is wanted on the bars, the time of keeping them red hot must not be so long. If heated a few moments only, the skin that would be hardened by quenching is very thin, and the rest of the bar inside the skin which has been carbonized is soft, tough, and pliable as the iron was before. Hence, the name "case hardening." It is useful for a very important class of work where hardened surfaces are desired, backed up by material that will not break easily. Steel that is so low in carbon that it will not harden properly is easier to forge or machine into desired shapes, and for many reasons is often manufactured into pieces that should have all parts of the surface hard. This material, as well as wrought iron, can be case hardened by carbonizing it to sufficient depth and treating it for hardness the same as high carbon steel.

Carbonizing Materials

Wood, charcoal, bone, leather, and cyanide of potassium are each used alone or as mixtures; bone and leather mixed do not give good results; wood charcoal, or cyanide will mix with either of them and give good results. Pure carbon does not act in a vacuum, and, as the pieces should be covered in the box to prevent the oxidation of the air from hindering the result, sugar, which is a pure carbon, will not carbonize the piece unless some other substance, like bone or leather, is mixed with it. Carbonizing gases can be used, and where much work with large or odd sized pieces must be carbonized, a furnace designed to heat and conduct the carbonizing gas upon them may be installed.

The carbonizing is well done by packing the pieces in a cast iron box with granulated bone, leather, hoofs, or wood charcoal. The box should be closed and the air excluded by stopping all cracks with clay. This should be kept red hot for some time, not less than an hour for much depth to the hardened skin. A quicker way is to heat the pieces in the fire, cover the surface of the part to be hardened with cyanide of potassium, reheat until the cyanide melts, then quench it in water. Its surface will be made so hard that a file will scarcely scratch it. But a better way to use the cyanide is to

melt enough to cover the pieces in a cast iron box large enough to receive them. Then by keeping the material in the box red hot for an hour or more, the depth of penetration will be considerable.

Pieces that have been polished may be hardened and colored by taking them out of the cyanide bath and dropping them into clear water.

The subject of coloring with case hardening belongs more properly with the subjects of tempering and annealing, which are treated of in the next chapter.

Depth of the Hardened Case

As seen in Fig. 10, the thickness of the hardened skin varies. The depth of penetration depends upon the time the pieces are kept hot, the temperature that is maintained, and the carbonizing materials that are used; as a rule, the hotter the pieces are, the faster the absorption of carbon will be, but too high a heat will cause the grains to grow large, and the excess of carbon absorbed just below the surface of the piece may make it brittle; a medium temperature, evenly maintained, and sufficient time in the heat, gives uniform absorption to any depth of penetration desired; the temperature should not be less than 1150° F. (a cherry red) for any steel; the proper heat for the kind of steel should be maintained for one hour to ensure a depth of penetration on wrought iron or machinery steel of 1/32″; alloy steels which contain the elements tungsten, chromium, etc., used for high speed tools, will absorb the carbon faster, while steels alloyed with aluminum, nickel, and some other elements, take in the carbon at a slower rate. The steels already high in carbon or other alloys are not usually treated by case hardening processes; low carbon steel, which is in composition about the same as puddled wrought iron, is the material of which most articles are made that require case hardening; for this the rate of penetration with good carbonizing material is about .03 of an inch during the first hour, .01 during the second and each succeeding hour. One hour of time after the pieces are red hot will carbonize the piece sufficiently for thorough hard-

Fig. 10.

ening to a depth of 1/32″. For double that depth of penetration, at least four hours of time would be required.

The pieces shown in Fig. 10 were taken from the carbonizing box and plunged into cold water; the first one had been at a full red heat for one hour, the second one for four hours. A distinct line of demarcation between the soft center and the hardened portion can be seen more distinctly in the second piece than in the first. This line may be a weak place in the piece, and the damage might have been avoided by annealing the steel after carbonizing, and then reheating it for hardening.

LAWS OF HARDENING STEEL

1. **Carbon tool steel,** heated and quenched in water or other cooling bath until cold, will be hardened and its structure changed or grain refined (small crystals) according to the heat and cooling rate.

2. The right hardening heat for any steel is fixed by its chemical constituents.

3. The hotter the steel and the more sudden the quenching, the more coarsely crystalline will be the fracture.

4. To prevent change of carbon, tools may be heated in melted glass, salt, or lead.

5. Water is a quick quenching medium. It should be kept clean.

6. Oil and grease do not cool the metal as rapidly as water.

7. Mercury or brine cools the metal more rapidly than water.

8. A quick heat and a cold bath may cause the steel to crack, or change on the outside, but not in the middle.

9. Rapid cooling gives the status quo, the state into which the steel was brought by heating; sudden quenching fixes the hot condition, making the metal in the cold state show itself as it was when hot. (This has from time immemorial been accepted by toolsmiths as the cause of hardening).

10. The proper hardening heat color, which varies with the carbon content of the steel, can be seen best in a dark room.

The subject of hardening as it has been explained and illustrated is condensed here. This guide is intended to serve for handy reference by those engaged in such work.

GUIDE FOR HARDENING

	COLOR OF HEAT.	DEGREE F.	RESULTING HARDNESS.		APPEARANCE OF FRACTURE.
1.	Bright Yellow or Cream White...	2200	Excessively hard and brittle.	Too Brittle for Tools.	Grain Coarse. Crystals large. Lustre brilliant.
2.	Yellow or Lemon.....	1800	Extra hard. Will break easily.		Grain large and sparkling, but not so brilliant.
3.	Bright Red	1600	Not strong enough. Edges crumble.		Grain not so coarse, but with bright lustre.
4.	Clear Full Red or Bright Cherry.	1400	Very hard.	Used for Tools.	Grain refined, crystals small. Some sparkle.
5.	Fair Red	1200	Hard and strong.		Fine grain, no sparkle.
6.	Low Red or Cherry Heat.....	1100	Very strong and hard.		Grain fine and close.
7.	Blood Red or Dark Red.....	1000	Hard and tough.		Very fine grain, good structure.
8.	Dull Red or Black Heat.....		Stronger than the bar. Not hard enough.		Grain same as in the bar.

Steel containing less than one per cent carbon may be properly hardened in water at a heat as high as No. 4 or No. 5; that containing more than one per cent carbon will harden properly at a lower temperature, indicated by color No. 6 or No. 7, in oil or water.

High speed or alloyed steel must be treated at high heats, according to instructions given by the manufacturer.

CHAPTER X

SOFTENING STEEL AND IRON

TEMPERING

A steel tool that has been properly hardened may be so brittle that its edges would crumble or break down in service; it is therefore necessary to temper it. The most common way to do this is to rub the piece with sandstone, or polish it, and then watch for the change in color as it is re-heated, either by a surplus heat left in the body of the tool when the cutting edge was hardened, or by holding it over a hot plate or metal, or in the gas flame, or over the coals of a fire. There is danger of gas or smoke stains by the last named methods of re-heating, and it is essential that temper colors should be seen and produced in clear air, or they will not be a true guide to the hardness left in the steel. Under the right conditions, the color test is a certain indication of the temperature of iron or steel, and this changes the hardness or reduces it to the point desired. The process can be learned and followed safely by careful attention to the *guide for tempering.* See pages 158, 159.

It is not necessary to have steel of the carbon content set opposite each tool named in the guide in order to make good tools, for any of the high carbons may be used for fine edged tools, and any of the low carbons would answer for the others. The list is given to serve the purpose of a guide to the selection of stock, as well as to the range of hardness best adapted to various purposes.

HEAT TREATMENT SUMMARY

.50 to 2.00 Carbon Steel heated to the right shade of red (900 to 1400° F.).

- *Cooled slowly* as possible in dry lime or ashes, is *Annealed.*
- *Cooled quickly* as the kind and shape will stand in Mercury, Brine, Water, Oil or Grease, it is *Hardened.*

When heated after hardening, 212 to 700° F. it is *Tempered.*

TEMPERING NOTES

1. Tempering is a reduction of hardness caused by heating to not more than 700° F.
2. The ductility and elasticity are restored or increased by temper.
3. If heated by induction, a rapid rise in temperature does no harm.
4. The higher the tempering heat, the softer the piece becomes.
5. When steel is properly hardened, polished and heated, the color is a test of temper.
6. Tempering with oil prevents oxidation and increases the elasticity of the piece.
7. Defects may arise from adhering to any special process of tempering, because steel is not uniform.
8. Methods of hardening and tempering are often kept a trade secret.

OXIDATION COLOR

There are three groups of tempering colors, yellow, red and blue. All other colors named in the guide, on pages 158 and 159, or that may be seen by the temperer, are combinations of these three, and there are some curious facts that should be mentioned here in order that a beginner may not be deceived. It makes no difference in the temper color whether the piece was excessively hardened, properly hardened, or only partially hardened. Even if it were not hardened at all, temper color can be drawn just as well. It seems strange, too, that all of the colors can be made by heat and oxidation on the same piece at the same time in this way.

Heat a piece of polished hardened steel to about 400 degrees Fahrenheit, or until it has changed from a grayish white to a yellow. After allowing it to cool repolish three-fourths of the surface, and reheat to the same temperature, or until the same shade of yellow appears on the repolished part. The one-fourth yellow oxide that was not polished off, will be changed to red by this treatment. If this red quarter and one yellow quarter are left on a piece while the other half is again repolished, the whole piece may be reheated to the same temperature, and when the yellow comes on the polished parts, the red quarter will be changed to blue, the yellow quarter will become red, and one-quarter of the half that is yellow

may be repolished to the natural white or gray color of hardened and untempered steel. There in a single piece that has been subjected entire to the same heat treatment, are all appearances of high, medium and low tempers, but we know it to be all of equal hardness; the same in structure and condition throughout and unlike in appearance only.

So it is only the first temper colors that should be relied upon; the color at first reheating after proper hardening is meant in these instructions and given as an indication of the condition of the steel.

Some graduation of hardness might be made by repolishing and reheating for second yellow, third yellow, or red or blue, but shades and tints of these colors are simpler and well known to men of experience, and take less time to produce.

JUDGING TEMPER BY COLOR

The surface of metals is liable to oxidation at low temperatures. Iron surfaces that are polished become blue when exposed to the atmosphere at a temperature considerably below red heat. If the heat is applied slowly while the surface is watched, it may be seen to change, first to a light yellowish color which becomes gradually darker as the surface is made hotter. This action of the air upon the polished surface of the steel is useful to a temperer, as it furnishes him a guide for reducing the brittleness of steel the required amount and retaining the other properties of the hardened piece with its structure unchanged, unless the piece is heated higher than 700° F.; below this heat the blue oxide has been formed, but is driven off at this temperature, and will show itself again and quickly disappear if the surface is repolished.

The guide names the most reliable and certain colors in their order with the temperature at which the same condition would be caused without oxidation, if the steel was heated uniformly away from an oxidizing atmosphere. It should also be remembered that many combinations of these colors may be observed on surfaces variously polished, or when the heat is checked at points between the given temperatures. This is especially true of the violet which leaves red spots on the blue if the piece is heated about 580 degrees. There is also a mixed color known as peacock, which appears if the conditions are right, between 500 and 580 degrees; but to those familiar with this process, it is well known that closer

graduation by the color test is of little value except for special work on known grades of steel.

When polishing tools that are to be tempered by allowing the surplus heat in the stock to run out into the bit after it has been hardened, the portion of the tool to be tempered should not be in contact with metal, but held in a position like that shown in Fig. 1, where all sides of the bit are exposed to the air without being chilled by any other substances. After the bit of the tool is thoroughly cooled in the bath, the water or oil will remain on it until the polishing is partly done; if the moisture dries quickly, it indicates internal heat left in the bit that may reduce all hardness of the surface, and that

Fig. 1.

it was not cooled in the center enough for proper hardening. In this case *false oxidation colors* may appear and be rubbed off with the polishing stone to be replaced by a true color that is not an indication of the highest heat to which the bit was raised. But when sufficiently cooled by the hardening bath there is time to polish a strip along one side of it; particular care should be observed to have a bright spot at the place where the rubbing stone is in Fig. 1.

All of the temper colors may appear at this point; yellow in advance extending faintly out to the end, a narrow streak of red oxide just back of it, with blue over the shoulder of the tool continuing back into the stock a half inch or more where it blends into a combination of all these colors,

making a false color if the piece was polished back close to the surplus heat that was left in the stock to draw the temper in the bit of the tool.

All tools in which temper is drawn immediately after hardening may be treated in a similar manner, if the stock or unhardened part of them will contain enough heat to raise the temperature of the cold hardened edges sufficiently.

When there is not heat enough left in the body of a tool to draw the temper on its edge, another piece of hot metal may be placed near enough to do so.

This way of drawing temper is also practiced with tools that must be quenched entire, and as there is no internal heat or other portion of the piece in condition to raise the temperature of the cutting edges, more time may be taken for polishing and the temper colors can be more clearly shown.

Sand heated in an iron vessel may be used with more precision than the piece of hot metal, and a thermometer in the sand will show the temperature, so it is not necessary to have pieces polished when this method is used. There is a good deal of uncertainty also about judging the tempered condition of steel by its color, except on work done by those of experience, and besides this the color of oxidation is not a function of the tempered condition of hardened steel, but an indication of the heat between the temperatures of about 400 to 600 degrees Fahrenheit. If a temperer polishes off a color that appears at, say, 500 degrees and then reheats the piece to a higher temperature, say, 550 degrees, indicated by a different shade of color, the effect would be about the same as though he had taken the higher temperature without polishing the second time, and it would make no difference except in the time taken to do the work, whether the steel was cooled or not before reheating.

But all the colors that have been proven and accepted as guides to the temperer, appear to chase each other from the polished surface, and show themselves at known temperatures; and the method of some temperers of re-polishing and re-heating a number of times may be suitable sometimes, but should not be adopted in common practice.

OIL TEMPERING

Heated oil may be used instead of sand, the temperature of the oil can not be made as high as the sand would endure,

and it deteriorates rapidly, but is excellent for tools requiring high temper. In Fig. 2 the cast iron crucible contains linseed oil ten inches deep, and is in a gas furnace where it was heated to 425° F.; a wire screen is placed four inches under the surface of the oil and the bulb of the thermometer rests on the screen where the toothed steel cutter was put after it had been hardened; the cold steel cooled the oil down to about 400° F. and the gas fire brought it slowly up to 425° F. again, when the cutter was taken out tempered the same as if it had been polished and drawn to a straw color.

Fig. 2

The treatment for articles hardened in oil, may be changed by making the oil that adheres to them from the quenching bath burn off as the piece is held in a flame. Some experience is required before the results of this method can be made very accurate, as the quality of the oil and its rate of burning must be taken into account. For some springs, gears, and forgings, it is an excellent method, but is dependent on the skill of the operator.

OIL TEMPERED FORGINGS

Forgings of machinery steel may be toughened and strengthened by heating and quenching in oil; as this kind of steel will not properly harden the treatment is called oil tempering.

OTHER LIQUID BATHS AND METHODS

Mixtures of tin and lead which melt at the tempering heat wanted for the tools, may be made and used, either as test bars to prove the heat to which a piece is raised, or as liquids in which to heat the steel for tempering, as was shown with oil in Fig. 2.

Salt baths are sometimes used where the drawing temperature is desired at 575° F. Salt fuses at this point, and a certainty of obtaining this temperature in the steel is assured. In using this the salt is heated to 700 or 750 degrees and the steel placed in the bath. When this is done the cold metal will cause the salt which surrounds it to solidify and plainly show a white crust around it. When the steel has obtained a temperature of 575 degrees the white crust will disappear as the salt which made it has melted and mixed with the rest of the bath. This clearly shows that it is time to take the piece out of the bath and allow it to cool. Salt can be used for tempering above 575 degrees and below 900 degrees, but is not practical for higher or lower temperatures, owing to the alteration in the salt.

Gas, oil, electric or other furnaces may be heated to the temperature desired for tempering, and maintained at that heat measured with a pyrometer, if the tools are placed in a muffle where they are not injured by the products of combustion; these methods can be kept under the control of a competent foreman, and not much dependence needs to be placed in operators whose carelessness might spoil valuable lots of tools. Where large numbers of pieces are required to be hardened and tempered alike, the best equipment, which is a combination of scientific appliances and experienced operatives, should be used.

VARYING THE RATE OF COOLING WHEN HARDENING

This is sometimes confounded with tempering methods. The confusion of partial hardening, with genuine tempering, must be avoided. The slow cooling mediums partly harden steel and may make it as good as it needs to be for some kinds of work, but the right heat and a quick cooling are necessary to produce the best structure in steel. If this causes more hardenite than is useful in the tool, it may be changed back into pearlite by the slight reheating called tempering. This change begins as soon as the lowest tempering heat is reached and continues as the heat increases. So it is not necessary to hold the piece at the tempering heat any length of time, nor to cool it quickly. The desired reduction of hardenite is accomplished as soon as the piece is hot enough, and no further change takes place if it is kept hot for hours. When the piece is wanted at once it may be plunged into cold water

to cool it for handling; otherwise it would be better to let it cool in a dry place in air, for seasoning and rest is a safe and good treatment to give steel of any kind or condition.

SPECIAL TEMPER

Some things can be tempered correctly by experienced workmen with nothing but their feeling and sense of time to guide them. The pieces heated for hardening are held with a light pair of tongs and submerged in the quenching medium; the sensitive hands feel the singing or tingling of the rapidly cooling steel, and when it has continued long enough, it is taken from the bath with just enough internal heat left to temper the piece without further treatment. Some kinds of toothed cutters or hollow reamers are quenched in water until the tingling of the steel has nearly ceased, then taken out and immediately put in cold oil for tempering by the internal heat of the piece; or the process is reversed by quenching first at the slower rate of oil and finishing in water.

EFFECT OF TEMPERING HEATS

At 212° F. the hardening strains are relieved and some hardenite has followed its natural impulse to return to the pearlitic state. The properties that were exaggerated by the hardening process are partly corrected. This correction will be complete in carbon tool steel a little above 600° F.

Low carbon steels of which machine forgings are made, crank shafts, gears, carriage springs, etc., which are subject to great shock, torsion and vibrational strains, are made stronger, tougher, or more elastic, grain size is restored, and the tension of parts strained when forging, is relieved by heat treatment, and they will be best fitted for their work when reheated for temper to about 700° F. Between these limits of temperature, all tempering is done, and as the color test is not reliable above 600°, other means are devised for knowing the heat in some pieces to be tempered.

CASE HARDENING FOR COLORS

The steel must be polished smooth and bright if fixed oxidation colors are desired when case hardening. If the pieces have been allowed to cool after being carbonized, they must be reheated and then quenched suddenly, the same as

ordinary tool steel must be treated for hardening, but it is common practice to plunge them in cold water as soon as they are taken from the carbonizing furnace; and this latter method is followed when case hardening for color. If they have been well polished, and are packed in powdered charcoal, bone or leather, all the contents of the box may be dumped into the bath, and some oxidation colors, gray, yellow, red, blue and black may be well fixed on the surface of the metal. Brilliant colors are obtained by heating the pieces to a bright, cherry red in a cast iron box of sufficient size to contain melted cyanide of potassium enough to cover them. Take them out of the box one at a time with tongs, and drop them instantly from a foot or more above the tank into clear water with air bubbles coming up from the bottom, as shown in Fig. 3. The wrench is ready to drop onto the wire screen in the water. The coloring will be light with too much grey, if the steel is overheated, and dark colors result when the heat is not high enough; a fair red heat of 1250° F. gave the best coloring to the pieces illustrated. The lid of the cyanide box in the mouth of the furnace, Fig. 3, is raised enough to get the pieces out while the fumes are carried away by the hood over the furnace.

Workmen must beware of the splash of poisonous cyanide which flies when water from damp tongs gets in the box, and when the film of cyanide is suddenly dashed off as the pieces strike the water; hot cyanide will burn and poison the flesh so that recovery from a deep wound is doubtful. The fumes of the stuff are also deadly if taken in much quantity, but with care the material may be used with definite and perfect results for color and effects. The low cost and non-poisonous nature of the other materials makes them preferable in many cases.

ANNEALING

The operations which are the reverse of hardening, may have a similar effect on the structure of steel, and when the art of hardening is well understood, it is not difficult to learn how to reduce the ordinary hardness of steel to the least possible point, which is annealing, or to stop the reduction at any point, which constitutes tempering.

The annealed metal is in the softest condition for that metal. It has only the normal strength for material of its quality. All of its properties are in repose. It is, therefore,

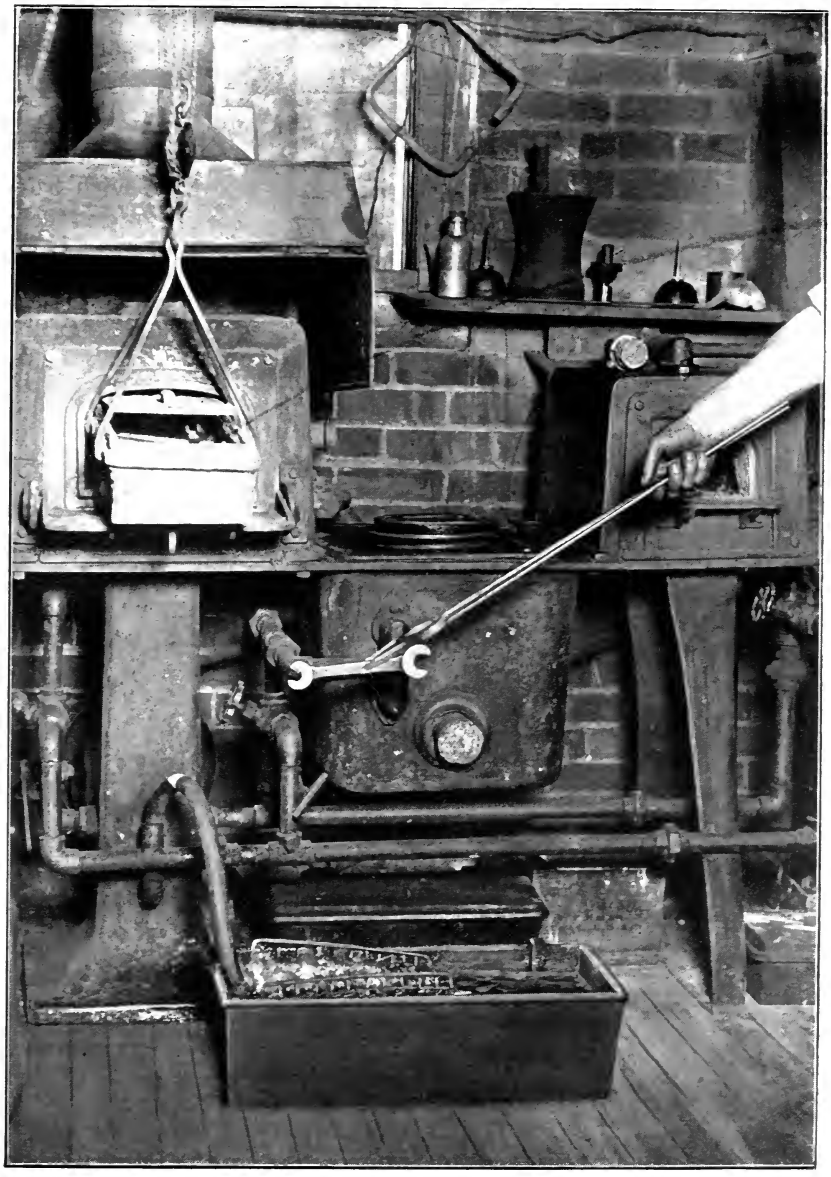


Fig. 3.

not high in tensile strength, and the elastic limit is as low as possible, but elongation and ductility are high, and it is as malleable as metal of its kind can be made.

ANNEALING HEATS

It is not necessary to harden a piece before annealing it, for its grain size will be fixed right by the proper annealing heat. This heat varies as does the hardening heat with the carbon content of the steel. For thorough annealing, the steel must be heated to exactly the same temperature as for hardening, and just as great care should be taken in the heating; but as the pieces do not have to be taken suddenly from the heat to the cooling bath, simpler methods of heating, so as to avoid oxidation and scaling, can be followed.

One of the easiest ways to heat small pieces or rods is in a gas pipe with both ends plugged to prevent circulation of air. If pulverized charcoal is packed around the piece of steel in a pipe or box, it can be heated and annealed without any injury from oxidation. Very high carbon steel should be heated to blood red, about 1000 degrees F., and low carbon may require a yellow heat which comes at 1600° F., before it will be properly annealed; that is, put in its softest condition when cold.

COOLING

The cooling rate for annealing must be as slow as possible, down to 400° F. Below this temperature no hardenite forms. Water annealing, as sometimes practiced, is done by cooling the metal in water as soon as it has fallen from the red heat of transformation to a temperature that shows red in a dark room. This arrests the seasoning in air to a normal condition and keeps the steel soft enough for ordinary machine shop practice.

True annealing is unlike hardening, where the cooling must be as fast as possible for maximum effects; here it must be slow. At least twelve hours should be given for the cooling of any piece of steel that needs thorough annealing, and if the piece is large, more time should be given. A piece five inches in diameter should have twenty-four hours' time. Pieces that are small enough to go inside of a three-inch gas pipe packed full of charcoal or brick dust, may have their cooling rate retarded so much that they will feel quite warm

to the hand twenty hours after they are taken from the fire. This is accomplished by burying the pipe or box and contents in air slacked lime three or four inches. There is no better method than this. Many poorer ways have been recommended and some of them are dangerous. Pieces left in the furnace are liable to accidental overheating, or at least may retain the highest temperature they ought to get, for too long a time. This is wrong. As soon as steel is hot enough, it ought to begin cooling slowly. Its cooling rate should be retarded. This is a very different thing from holding at a high temperature for a long time, where it is not at rest, and liable to injurious chemical action on the new formed grains. The change in structure releases all grains which may have been formed in the piece by former treatment, and the slow cooling allows the crystals to adjust themselves in all parts alike.

After each process in manufacturing steel parts that are expected to be exact in size and shape, they should be returned to their normal condition by annealing. Bending, twisting, or rolling sets up strains among the crystals. Machining takes off part of the material and may leave that which remains in a tension so severe as to warp or break it when hardening. Hammering and cold rolling distorts the crystals and crushes them together. In this deformed state the metal is sometimes harder and stronger than when in its normal condition, and is used for shafting, springs, and similar things, but the compression and increased density must be relieved before the metal can be safely treated for hardening, or machined into shapes it is expected to keep.

GUIDE FOR TEMPERING

Carbon Tool Steel, after hardening, may be tempered (i. e., its hardness reduced) as desired by slowly heating it to the proper temperature. This heating alone decides the temper; the manner of subsequent cooling has no effect on hardness. The degree of heating is determined by (a) or (b).

(a) The color of the oxidation of the surface, when the steel has been polished and is heated in the open air.

(b) The thermometer in the heating furnace or in the hot fluid (as oil, tallow, lead, etc.) in which is placed the hardened steel, either polished or unpolished.

OXIDATION COLOR.	DEGREE "F."	TEMPER.	FRACTURE.		SOME APPLICATIONS.	CARBON IN STEEL ABOUT
No Color,	300				Lathe Tools, special use	1.20 to 1.50
					Hand Turning Tools for metal	1.00 " 1.40
					Milling Cutters and Lathe Tools for brass	1.20 " 1.40
					Burnishing Tools	1.20 " 1.40
					Embossing Tools or Dies, Glass Drills and Cutters	1.25 " 1.40
					Mandrels, Machinists' Scrapers	1.00 " 1.25
Light Yellow,					Ball Bearing plates	1.00
1. *Yellow*,	400				Dies for press forging	1.10
Light Straw,		Very High			Planer Tools for steel	1.20 " 1.50
Straw,	425				Lathe Tools, regular use	1.05 " 1.15
Dark Straw,					End Mills	1.20 " 1.50
					Milling Cutters for steel and iron	1.20
					Taps and Threading Dies	1.20
					Flat Drills	1.20
					Lathe Centers	.90
Orange or Gold	450	High			Draw Knives for wood	1.20
					Cutting Tools for bone and ivory	1.25
					Scissors	1.00
					Ball Pene Hammers	.80
Brown with Red Spots	480				Hack Saw Blades, Pipe Cutter	1.05 to 1.20
2. *Red*,	500	Medium			Circular Saw for steel	1.60
					Reamers	1.20
					Shears for metal	1.10
					Drop-Forging Dies, Corn Knife, Mattock	.90
					Drill Bits for stone	.80

AS HARDENED

Wine Color with Blue Spots,	530		GRAIN REMAINS	Surgical Instruments	1.25
Purple,	550			Some Woodworking Tools, as Chisels, Knives, Jointers, Planer Blades and Turning Tools	1.25
Violet or Peacock,	565	Mild		Some Woodworking Tools as Axes, Carving Tools	1.00 to 1.10
				Augers, Butcher Knife	.80 " .90
				Circular Saws	1.15
				Pocket Knife	.90
				Shell Reamers	1.10
Blue with Red spots,	580	Low		Blacksmith Tools, as Flatters, Fullers, Swages	.60 to .70
				Pliers	.90
				Cold Chisels	.80
				Stone Chisels	.80
				Punches	.80
3. *Blue*,	600			Handsaws	.80 to 1.00
				Some Small Springs, Cant Hook	1.15
				Band Saws	.75 to 1.00
Changes	625			Quarry Drills, Wedge or Glut	.60 to .70
to		Very		Drift Punches, Wrenches	.60 to .70
Gray or Green,	650	Low		Chisels for cutting hot stock, Screwdrivers	.60 to .70
				Moulding and Cutting Tools to be filed	1.10
				Jaws for Pipe Machine, Wire Pullers	1.10
				Vise or Gripping Jaws	.90
				Some Large Springs	1.25
Shows red heat in the dark,	750	Soft, No temper remains.		This treatment improves the structure of steel and is best when done in oil.	
Black Oxide forms here.	800				

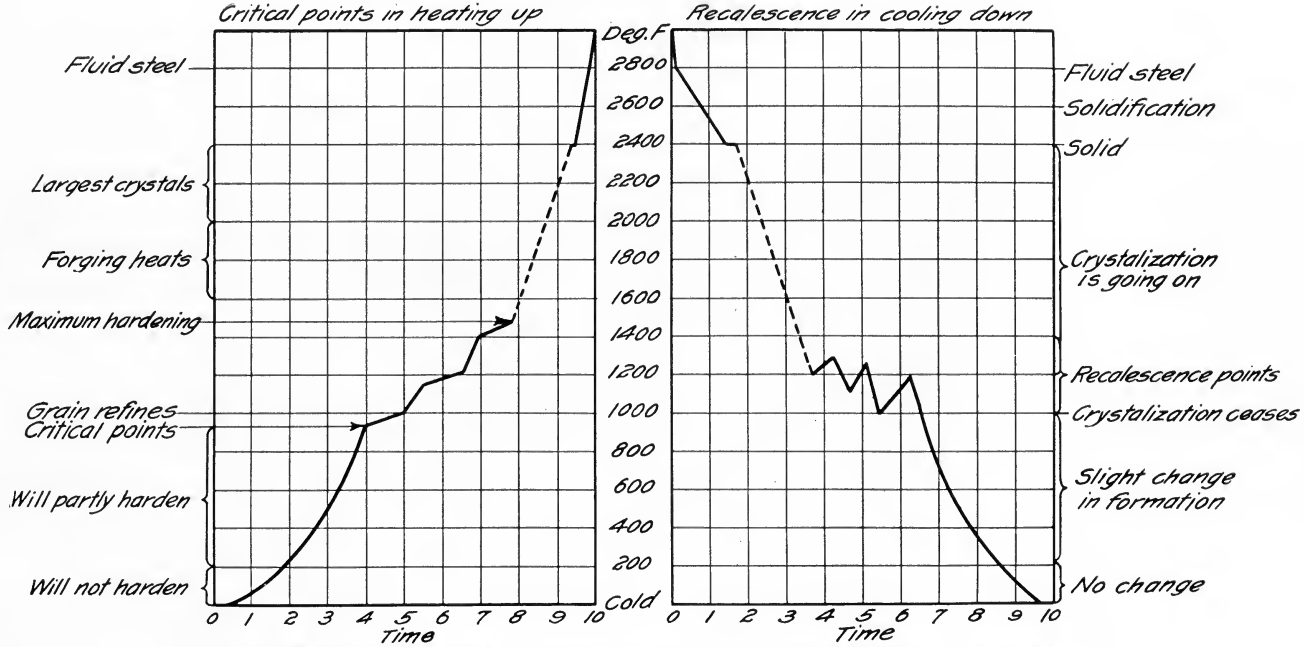
In this classification, the carbon content of the steel for each tool is considered about as recommended; should the percentage of carbon in the steel be otherwise, the temper color should be accordingly varied. In general, if the carbon percentage is low for the kind of tool, the temper should be high; and if the carbon percentage is high, the temper should be low.

ADDENDA

For those who are interested enough to continue the study of metals, this chapter is added, with the purpose of encouraging them to study the science of metallography

COMPOSITE DIAGRAM

The temperature changes with the chemical composition of the steel.



The time periods indicate long or short duration, depending on the size of the piece that is heated or cooled.

CHAPTER XI

METALLOGRAPHY

Metallography is defined as the science of metals with reference to their structure. Little attention was paid to the subject of metallography twenty years ago, and not much has been written on the subject, but steel users know that the physical properties of steel depend largely on the thermal and mechanical treatment it has been subjected to. All industrial metals contain impurities, and chemical analysis may show the composition perfectly, but a treatment that changes the mechanical properties very much leaves the ultimate composition unaltered, and here where chemistry fails, metallography comes to our aid.

Information concerning the constitution of metallic alloys has been greatly increased during recent years. The Institution of Mechanical Engineers in England, and also the Society in France, appointed special committees for research in this field, and the excellent work of investigation has been followed by others in this country until the study of the structure of alloys by examination of fractures that have been subjected to certain heat treatment, polished, etched and placed under the microscope has created this new department of science called metallography.

Steel being now the most useful material will occupy the greater part of this chapter, and we will follow the work of Sauveur more closely than that of any other, as his careful investigations and clear language has placed him amongst the highest authorities on the subject. He considers steel (Fig. 1) as an alloy or mixture; all of the carbon combines with a portion of the iron, forming the carbide Fe_3C. This carbide being distributed through the mass forms a compound with a structure like other binary metallic alloys.

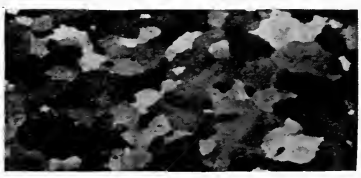


Fig. 1.

The analogy existing between the structure of frozen saline

solutions and metallic alloys is almost perfect, and both classes of substances are controlled by the same laws during the formation of their structure, i. e., while freezing. (Saline solutions being liquid, while steel is solid at ordinary temperatures, prevented an earlier discovery of the identity of the laws which govern the constitution of both substances). I give here a brief statement of these laws. By dissolving common salt (sodium chloride) in water we lower its freezing point, as we all know; further additions of salt make the freezing point still lower, until the water contains a certain percentage. After the lowest possible freezing point for this saline solution is reached, any increase of salt will raise the freezing point of the brine. Dr. Guthrie says that the solution of lowest freezing point is an hydrate of the formula $NaCl + 10\ H_2O$, as he found the lowest freezing point to contain about 23.50% NaCl. Such mixtures were named by him "cryohydrates."

Saline solutions begin to freeze at temperatures corresponding to the proportion of salt which they contain; they all finish freezing at the same temperature, viz., 22° C. (71.6° F), the freezing point of the cryohydrate. If we consider water as fused ice, and the ice of cryohydrates as mechanical mixtures of salt and ice, as has been proven by using colored salts and other means, we may say that solubility and fusibility represent the same thing; applying fusibility to mixtures solid at ordinary temperatures, and solubility to those liquid at those temperatures.

The theory of the constitution of metallic alloys divides them into three classes:

I. Isomorphus mixtures.

II. Definite compounds.

III. Alloys which form neither definite compounds nor isomorphus mixtures.

We are to consider one belonging to the third class, and there are two cases or conditions to be considered, viz., those mixtures which have the lowest possible melting or freezing point, corresponding to cryohydrates and named by Dr. Guthrie "eutectic alloys;" and those containing various proportions of two component metals.

The analogy existing between cryohydrates of saline solution and eutectic mixtures of metallic alloys is perfect, and

similar irregularities are observed in the cooling rate of alloys having a composition different from the eutectic mixture as with saline solutions which are not cryohydrates. For example, if silver is in excess of that required for a eutectic mixture of Ag and Cu, then when the cooling mass reaches a certain temperature the silver in excess begins to solidify (exactly as water would begin to freeze and continue to form pure ice until the remaining water and salt becomes of a composition corresponding to a cryohydrate). When the excess of silver has solidified, the separation of pure silver ceases; the cooling is arrested, or its rate retarded, and solidification of the alloy begins and continues at a constant temperature. This temperature is the point of solidification for the eutectic alloy, 770° C. (1418° F.) for a composition 28% Cu, 72% Ag, shown

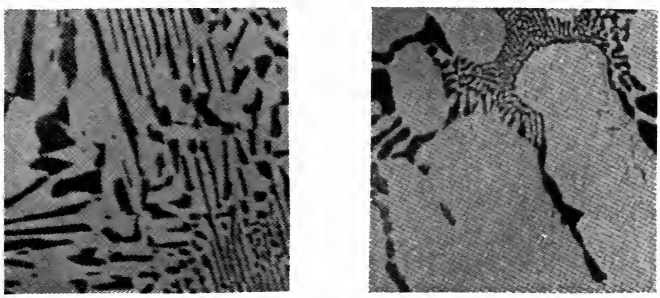


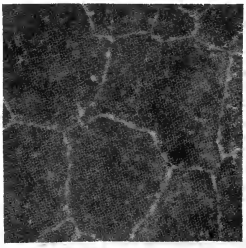
Fig. 2.

on the left in the illustration, Fig. 2; the one on the right is 65% Cu, 35% Ag. They are magnified 600 diameters.

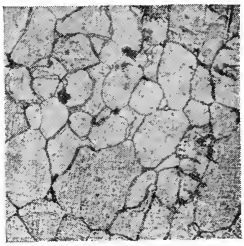
If copper is present in excess with regard to the composition of a eutectic alloy, pure copper begins to solidify at a certain temperature, this solidification of copper ceases and the cooling rate is momentarily arrested when the portion remaining liquid has reached a composition identical to that of the eutectic alloy.

Solids then containing a larger proportion of either metal than the eutectic alloy will be made up of crystalline particles of the one in excess, surrounded by the eutectic alloy. This matrix always has a definite composition and exhibits a close fracture, but the microscope shows it to be merely a mechanical mixture, of two constituents, in extremely minute crystals or plates in close juxtaposition.

The structure of iron and steel, shown in Figs. 3 and 4, will be understood by this reference to the laws which control the formation of structure in saline solutions and metallic alloys. By allowing samples of steel to cool from a high temperature and observing the rate of cooling by means of a pyrometer, when a certain temperature is reached which varies with the carbon content, a sudden retardation occurs which



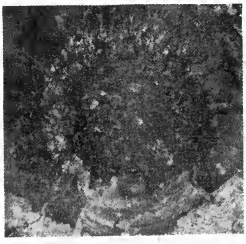
Mild Steel.



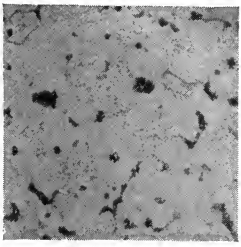
Rolled Iron.

Fig. 3.

denotes some evolution of heat. It is sometimes so intense as to produce an actual rise in the sensible temperature of the steel, a recalescence of the metal. This phenomenon, known by the name of "recalescence," and the temperature at which it occurs as the temperature or point of recalescence, is of vital importance; it is a critical temperature. In passing through



Broken Steel.



Hammered Iron.

Fig. 4.

it the steel is entirely changed, its physical and mechanical properties are altered. It is a phenomenon peculiar to iron and steel, and although the whole mass is solid at this temperature, the same separation of component parts takes place during recalescence as we have noted during the solidification of other eutectic alloys. Steel containing 0.80 per cent. carbon will at this temperature take the form or structure of a

eutectic alloy of iron and the carbide Fe_3C, a mechanical mixture with a structure made up of small crystalline plates or grains evenly distributed as a result of the simultaneous segregation of the two constituents. See drawings in Fig. 5.

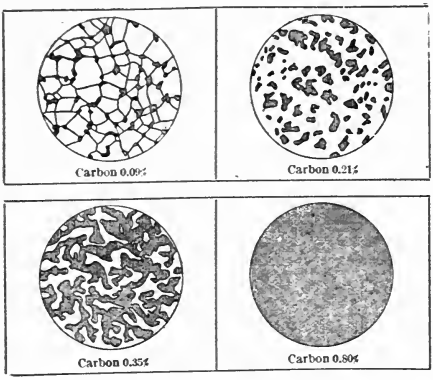


Fig. 5.

Steel containing less than 0.8 per cent, carbon (12 per cent. of Fe_3C) will be made up of crystalline grains of pure, or carbonless iron, in a matrix of the eutectic alloy of Fe and Fe_3C. Iron containing 0.8 per cent. carbon is all made up of the eutectic alloy, presenting all the structural characteristics of other eutectic mixtures, being alternate thin plates of Fe and Fe_3C seldom exceeding 1/40000 of an inch in thickness. The structure of these plates, pearlite magnified 1000 diameters, is at the right; and ferrite, magnified 130 diameters is at the left in Fig. 6.

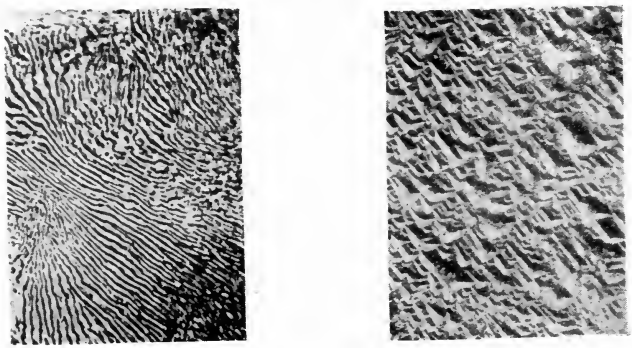

Ferrite. Pearlite.

Fig. 6.

Steel that contains more carbon than enough to form 12 per cent. of Fe_3C (carbide) has an excess of the carbide with regard to the composition of the eutectic alloy. As all the carbon combines with the iron, more than the right proportion of Fe_3C is present in the mass and areas of carbide surrounded by the eutectic alloy are seen under the microscope, as shown in Fig. 7, magnified 1000 diameters.

Mineralogical names have been given to these constituents. Pure iron is called "ferrite" and shows white in Fig. 8. The carbide Fe_3C, called "cementite" is black in Fig. 7. The eutectic alloy is called "pearlite." The composition of pearlite remains the same, like that of any eutectic alloy. It always contains 0.80 per cent. carbon. Ferrite and cementite can not be formed in the same metal. The relative proportions of ferrite and pearlite or of cementite and pearlite vary according to the degree of carbonization.

Low carbon steel, see Fig. 8, 0.45 per cent. carbon, magnified 1000 diameters, has a matrix of ferrite enclosing particles of pearlite. Increasing the carbon content increases the pearlite, until at 0.80 per cent carbon the metal is said to be saturated and is made up entirely of pearlite, having a

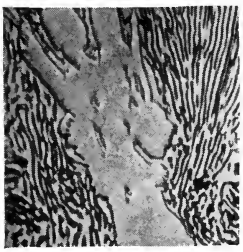


Fig. 7.
1.50 Carbon.

STEEL POLISHED AND ETCHED, SHOWING STRUCTURE NOT HARDENED.

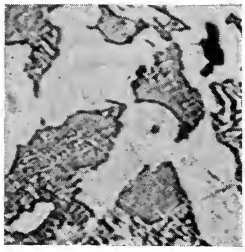


Fig. 8.
.45 Carbon.

pearly appearance (like mother of pearl). With further increase of carbon, cementite makes its appearance, increasing with the carbon content, and causing a corresponding decrease in the amount of pearlite. From its carbon content, the structural composition of any carbon steel may be calculated.

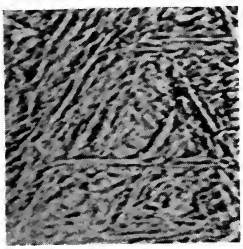
In saline solutions and alloys the rise in temperatures marks the beginning of solidification, the formation of structure takes place during a change of state, i. e., from a liquid to a solid.

Carbon steel is already in the solid state, and the heat evolved indicates internal energy, segregation of the constituents, without a change of state. This is suggestive, but not conclusive, of an allotropic transformation. It is the strongest argument of believers in the allotrophy of iron. It has not been possible to examine the structure of red hot metal, but by cooling the steel quickly, immersing it while at high tem-

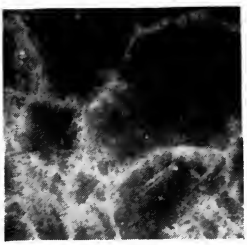
peratures in cold water, the changes, structural and others which take place during the retardations, do not occur, at least not entirely (for lack of time), and we retain in the cold metal the condition which existed at a high temperature. This treatment constitutes hardening, and we must observe the structure, or character, of hardened steel. With the microscope we see that 0.8 per cent., or saturated steel is now made up of another single constituent called "martensite," or hardenite, but if the steel was very highly carbonized we would see a mixture of martensite and "austenite," as in Fig. 9, while with 0.45 per cent. or low carbon steel hardened, we find, as might be expected, pure iron, or ferrite, and martensite in the structure after hardening, as shown, magnified 1000 diameters, in Fig. 10.

HARDENED STEEL

1.50 Carbon.
Fig. 9.



.45 Carbon.
Fig. 10.



.09 Carbon.
Fig. 11.

Fig. 11 is steel (0.09 per cent carbon) quenched at high heat, magnified 250 diameters.

Fig. 9 magnifies 1000 diameters a section of highly carbonized steel, i. e., 1.50 per cent., hardened. A new constituent may be observed here. This was named austenite by Mr. Osmand, and like the other names by which I have called the constituents of steel, this one is now generally accepted.

In steels quenched below the recalescence temperature, no martensite or austenite can be found; they are like annealed steel in their microstructural composition, and we know they are not sensibly hardened.

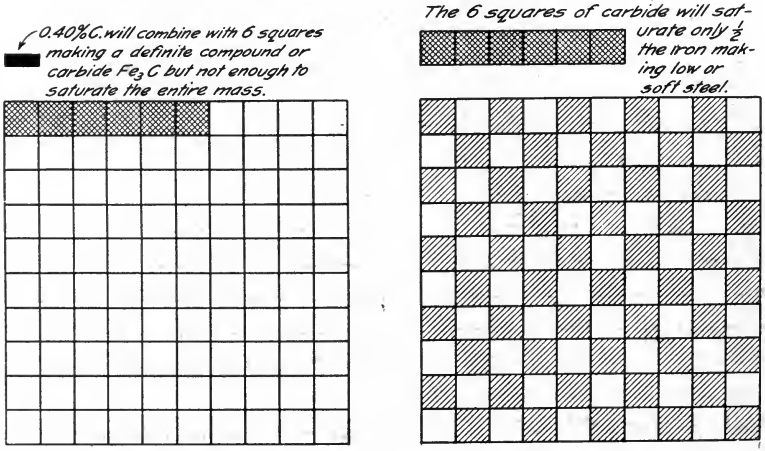
This remarkable effect of heat treatment is well known, and the difference between the mechanical properties of steel suddenly cooled from a high temperature and those properties of the same metal slowly cooled from the same temperature

is evidently due to the presence of martensite, hardenite and austenite. But the cause of the hardness of martensite remains to be determined, and is a subject of investigation. Mr. Sauveur says it is reasonable to suppose that martensite is a solid solution of carbon in iron, or of the carbide Fe_3C in iron, and abandons the theory of a definite compound of iron and carbon.

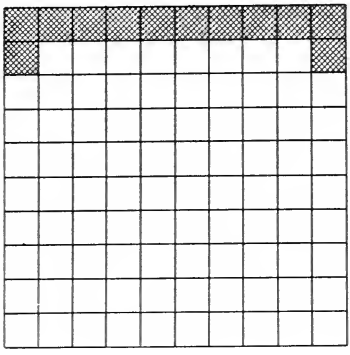
The allotropic theory is more plausible, iron itself is hard, and martensite may be a solution of carbon or Fe_3C in an allotropic condition of iron.

The physical properties of iron and steel do not depend on the relative proportion of their constituents, or upon the carbon content, but more largely upon the distribution, mode of occurrence, size and shape of the individual grains or crystalline particles. These characteristics are controlled by the treatment the metal is given. Slight changes of treatment, either thermal or physical, alter the structure, and the value of the microscope which supplies the means to determine those structural changes related so closely to the properties of metal has not been over estimated.

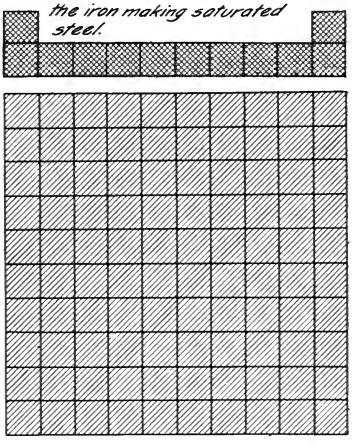
Theoretical drawings showing how iron and carbon mix forming different structure in steel.


0.40%C. will combine with 6 squares making a definite compound or carbide Fe_3C but not enough to saturate the entire mass.
The 6 squares of carbide will saturate only ½ the iron making low or soft steel.

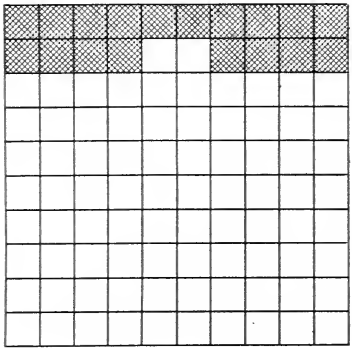
0.80% C. will combine with 12 squares making carbide enough to saturate all the iron.



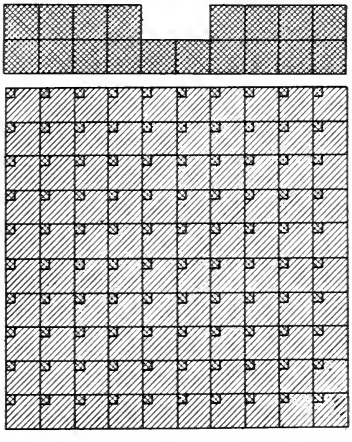
This carbide will saturate all the iron making saturated steel.



1.20% C. will combine with 18 squares making more carbide than enough to saturate the iron.



This carbide is more than enough to saturate the iron and mixes mechanically with the part that is saturated.



NOTES

One — At atmospheric temperature ferrite, which is pure iron, is called alpha.

Two — Ferrite is the largest element in any steel; it loses its magnetism at 1450° F. and is called beta iron while in this condition, and shows slightly in steel slowly quenched, and more plentifully in properly hardened steel that has been reduced by tempering.

Three — As it is made hotter, ferrite loses its electrical conductivity and absorbs heat rapidly; this condition is complete at 1650° F., where it is known as gamma iron.

Four — Alpha, beta, and gamma are the first three letters of the Greek alphabet; the names were given by metallurgists to the points where transformation occurs, with the rise and fall of temperature, and known as recalescence points or critical temperatures.

Five — Hardenite, martensite, and austenite are names for that arrangement, mode of occurrence, and appearance of the grains in steel that has been quenched at high temperatures.

Six — Carbide of iron is called cementite, expressed by the formula Fe_3C, meaning three atoms of pure iron for every one atom of carbon.

Seven — Pearlite is a mechanical mixture of ferrite and cementite that looks like mother of pearl.

Eight — Sorbite is an imperfect development of pearlite and cementite, segregated, but not so intimately mixed as to become hardenite. It occurs in partly hardened steel and is made more plentiful in alloys.

Nine — Troostite is a formation composed of the other substances and shows slightly in steel slowly quenched, and more plentifully in properly hardened steel that has been reduced by tempering.

Ten — The chemical composition remains the same, but the temperature at which these changes occur in iron is disturbed by other elements mixed with it.

INDEX

Anvils, size and weight, 13-14.
Annealed metal, condition of, 154.
Annealing heat, and cooling rate, 156.
Air blast, 8.
Air hardening, 136.
Allowance for welding, 35.
Alpha-beta-gamma, 172.

Barium chloride melts for steel, 131.
Bessemer steel-making, 29.
Bending rings and curves, 33.
Blast —
  Opening, 7.
  Pressure, 7.
Blacksmith punches, 18.
  (with wood handles), 19.
Blacksmith hand-punch, 19.
Blast Furnace —
  Flux, 24.
  Fuel, 24.
Boring tools, 122.
Bolts —
  To calculate stock for upset head, 45.
  Solid forged head, 45.
  Material to use for, 45.
  To make upset head, 46.
  To make welded head, 48.
  Weld head, 94.

Carbide of iron, defined, 112.
Case Hardening —
  Definition, 141.
  Carbonizing, 141.
  Materials, 142.
  Depth of, 143.
Case hardening, colors, 153.
Calculating Stock —
  For rings, 34.
  For curves, 35.
  For hooks, 67.
  For hooks, 75.
  For chain links, 75.
  For bolts, 45.
  For angles, 41.
  For shapes, 38.
Cementite, 127.
Cementite, 168.
  defined, 172.
Chisel, description of, 19.
Chain-hook, design, 66.
  making, 68.
Chain-links, standard size, 77.
Chisel-making, 114.
Chemical action of impurities in water, 135.
Circumference of circles, 56.
Cold short material, 28.
Converted steel process, 29.
Cold shuts, how to avoid, 42.
Corner, to build up, 44.
Corner weld, reason for, 89.
Cockeye making, 95.
Coefficient of expansion, 63.
Crucible Steel —
  For cutting tools, 113.
  Effect of hammering, 113.
Crystals, will grow, 132.
Critical stage is at, 133.
Critical heat, diagram, 162.
Cryohydrate, 164.

Decimal equivalents, 55.
Designing ornaments, 36.
Drawing out sharp points, 41.
Drawing of iron and carbon mixed, 170.

Electric welding, 102.
Eutectic alloy, 165.
Expansion of iron and steel, 36.
  linear in 6″, 59.
Extrusion process, 99.

False oxidation color, 149.
Ferrite, 127.
Ferrite, 168.
  defined, 172.
File-testing, report of, 109.
Fire for welding, 91.
Fluxes, sand, dolomite, glass, 86.
Flatter, 17.
Flux, using, 101.
Forge —
  Construction, 5.
  Fire, 5.
Forging by extrusion, 99.
Formula for hook stock, 75.
Fracture, appearance, 132.
Fuller —
  Top, 17.
  Bottom, 17.
Fuel, for forge fires, 8-9.

Gauge, U. S. and Birmingham, 53.
Grab-hook stock, 75.
  forging, 72
Grain of Steel —
  Coarse, 131.
  Refined, 131

Grinding —
Cold chisel, 18.
Hot chisel, 18.
Guide —
For hardening, 145.
For tempering, 158.

Hammers —
Origin of, 10.
Patterns of, 11.
In service, 12.
Hardie, description of, 18.
Hardenite, 127.
Hardenite —
Martensite and austenite, 169.
defined, 172.
Hardening —
Steel, 128.
Finished at, 134.
Tools, 126.
Cracks, 137.
Hardness —
Degrees of, 128.
Cause of, 170.
Heading tools, size of, 20.
Heat —
Definition of, 62.
Color names, 111.
Refines steel, 132.
Heat treatment, summary, 146.
High Speed Steel —
Classified, 25.
Composition, 136.
High speed tools, 123.
forging, 140.
hardening, 141.
Horse-power and B. T. U., 64.
Hot flame welds, 104.
Hot short material, 28.
Hoist hook stock, 75.

Iron-making, 26.
Iron —
Common, 27.
Swedish, 48.
Strength of, 58.
Melting point, 64.
Strength of, 51.

Lathe Tool —
Forging, 116.
Clearance angles, 117.
Bent shapes, 118.
Offset or twisted edge, 119.
Lathe tools, with shanks, 121.
Lead melts for steel, 131.
Light forging, 102.
Liquid baths for temper, 151.
Loss of Material —
When welding, 34.

Material for Forgings—
Kinds of, 22.
Conditions of, 32.

Machinery steel-making, 29.
Machine tools, 123.
Magnetic properties of steel, 134.
Melting Temperature —
Of metal, 64.
Of solder, 65.
Mercury bath for steel, 134.
Metallic salts for steel heating, 131.
Melt welds, 104.
Metallography, defined, 163.
Mushet Steel, 139.
Muffle furnace, 139.

Nut-making, 48.
Nuts, size of, 49.
Oil hardening, 135.
Oil temper, 151.
Open hearth steel, 29.
Ornamental work, tools for, 37.
Ornaments, designs for, 100.
Oxyhydrogen welding, 104.
Oxyacetylene welding, 104.
Oxidation —
Value when excessive, 105.
Scale peels, 129.
Effect of, 8.
Color, useful to temperer, 148.

Pack hardening, 139.
Pearlite, 127.
Pearlite, 168.
defined, 172.
Planer tools, 125.
Properties of wrought iron, 30.
of steel, 30.

Recalescence, defined, 166.
Recalescence, 134.
diagram, 162.
Reference tables, 51 to 65.
Rings, stock calculation, 33.

Salt melts for steel, 131.
Salt for tempering, 152.
Salt water, cooling rate, 135.
Scaling heat, 130.
Scarf for lap weld, 96.
Set hammer, 17.
Self-hardening steel, 123.
Seasoning steel, 126.
Slotter tools, 125.
Socket wrench making, 99.
Sorbite, defined, 172.
Springs, hardened, 136.
Spot welding, 103.
Squirting method of forging, 99.
Steel —
Use for, 31.
Cost of, 31.
Size of stock, 32.
Stretching a piece of material, 39.
Strength of steel, 52.
Strength of hooks, 80.
of links, 81.

Steel —
Welded to iron, 101.
Skin forged, 126.
Effect of grinding, 126.
Hardening cracks, 126.
Steel hardens, why? 126.
Steel —
Structure of, 127.
A perfect compound, 127.
Heated in bath, 130.
Effect of overheating, 131.
Refined by quenching, 131.
Refined by hammering, 131.
Transformed, 134.
Structural characteristics, 167.
Swages —
Top, 16.
Bottom, 16.

Take-up in rolling or bending, 36.
Tensile strength of metals, 51.
Tests —
For hooks, 77-78.
For chain, 78.
Tempering, definition, 146.
Temper colors, 147.
Tempering —
In oil, 150.
In hot sand, 150.
Temper, judged by melt bar, 151.
Tempering —
In gas, 152.
By varying the cooling rate, 152.
Tempering heat, effect of, 153.
Tempering, special methods, 153.
Thermit welding, 103.
Threading tools, bits bent, 123.
Transformation point of steel, 134.
Tongs —
Drop forged, 14.
Hand forged, 15-16.
Tool steel-making, 27.
Tool-smithing —
Time required, 123.
Size of tools, 124.
Tool Steel —
Changed by treatment, 112.
Heating right, 112.
Cut cold, 114.
Troostite, defined, 172.
Turn buckle making, 98.
Turning a hook, 71.
Tuyere irons, 7.
Tuyere, where located, 8.
Twisting —
Square stock, 73.
Effect of, 74.

Water —
Pure, for hardening, 135.
Cracks, in hardened steel, 126-137.
Welds —
Definition of, 85.
Kinds of, 87.
Test for strength, 103.
Safe load for, 104.
Welding —
Electric, 102.
Thermit, 103.
Hot flame, 104.
To build up a forging, 93.
Steel to iron, 101.
Welds, special kinds, 98.
Welding —
Cost of, 104-105.
Weight —
Of sheet steel, 57.
Of octagon, 57.
Of round, 58.
Of square, 58.
Of flat rolled stock, 60-61.
Wire, strength of, 51.
Wrought Iron —
Refined, 27.
Swedes, 28.
Use for, 31.
Cost of, 31.
Strength of, 51.
Size of stock, 32.

266993

Engineering
Library

UNIVERSITY OF CALIFORNIA LIBRARY